

THE  
INSTITUTION  
OF PRODUCTION  
ENGINEERS  
JOURNAL



JULY 1988

# THE INSTITUTION OF PRODUCTION ENGINEERS JOURNAL

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## CONTENTS

"BUSINESS FINANCING AND THE STOCK EXCHANGE" by Gordon Cummings 397

### THE 1957 GEORGE BRAY MEMORIAL LECTURE

"THE FABRICATION OF PLASTICS" by Dr. V. E. Yarsley, M.Sc.,  
D.Sc.Tech.(Zürich), F.R.I.C., F.P.I., M.I.Chem.E. . . . . 402

REPORT AND DISCUSSION . . . . . 442

"AIR GAUGING — HISTORY AND FUTURE DEVELOPMENTS" by C. J. Tanner 448

THE PRINCIPAL OFFICERS, 1958 - 1959 . . . . . 463

NEWS OF MEMBERS . . . . . 464

OBITUARY — Mr. F. T. Nurrish, M.B.E., M.I.Prod.E. . . . . 465

HAZLETON MEMORIAL LIBRARY — Additions . . . . . 466

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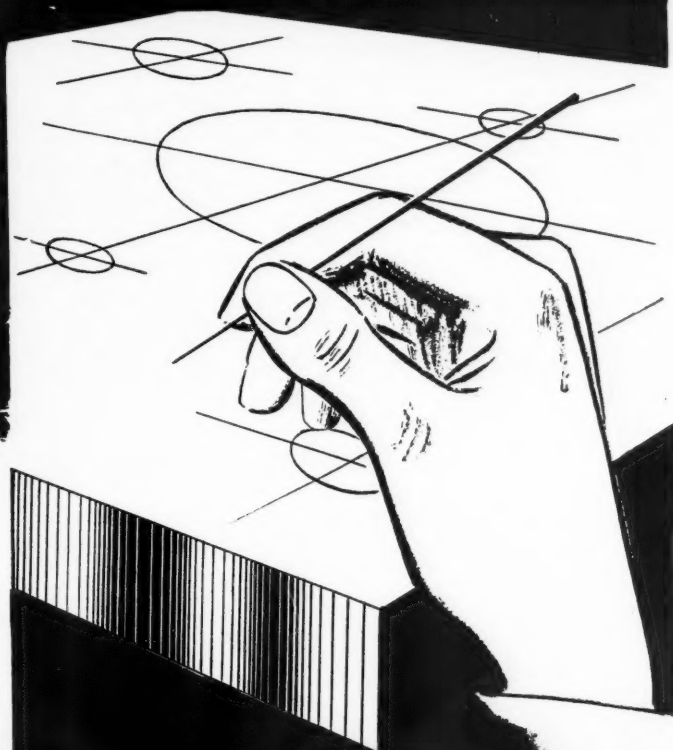
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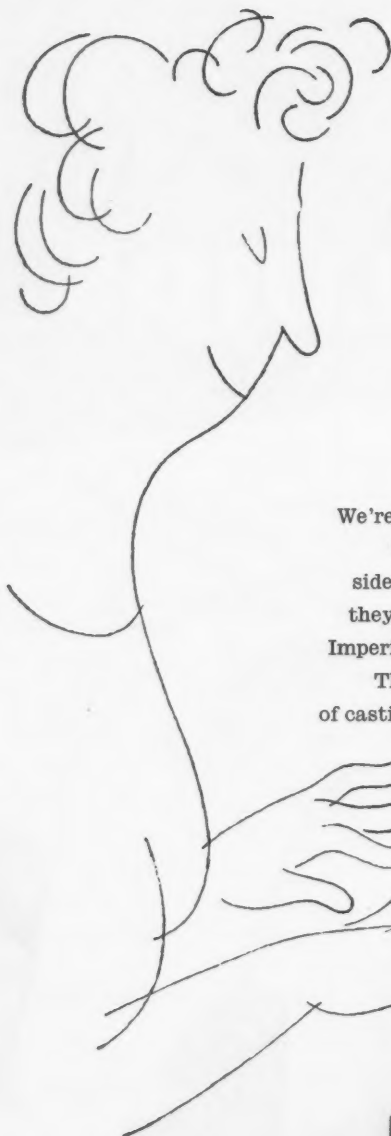
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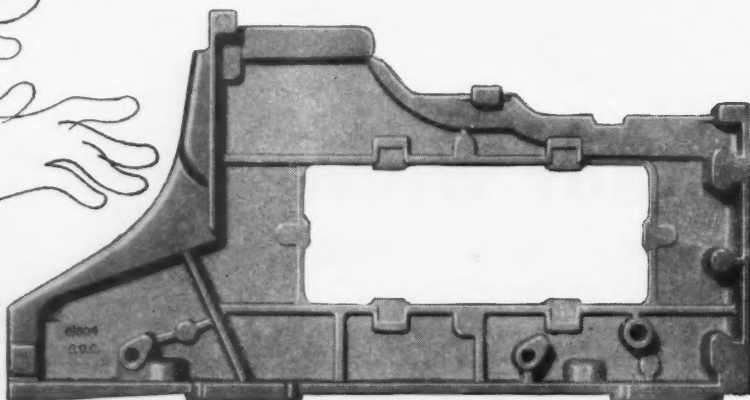


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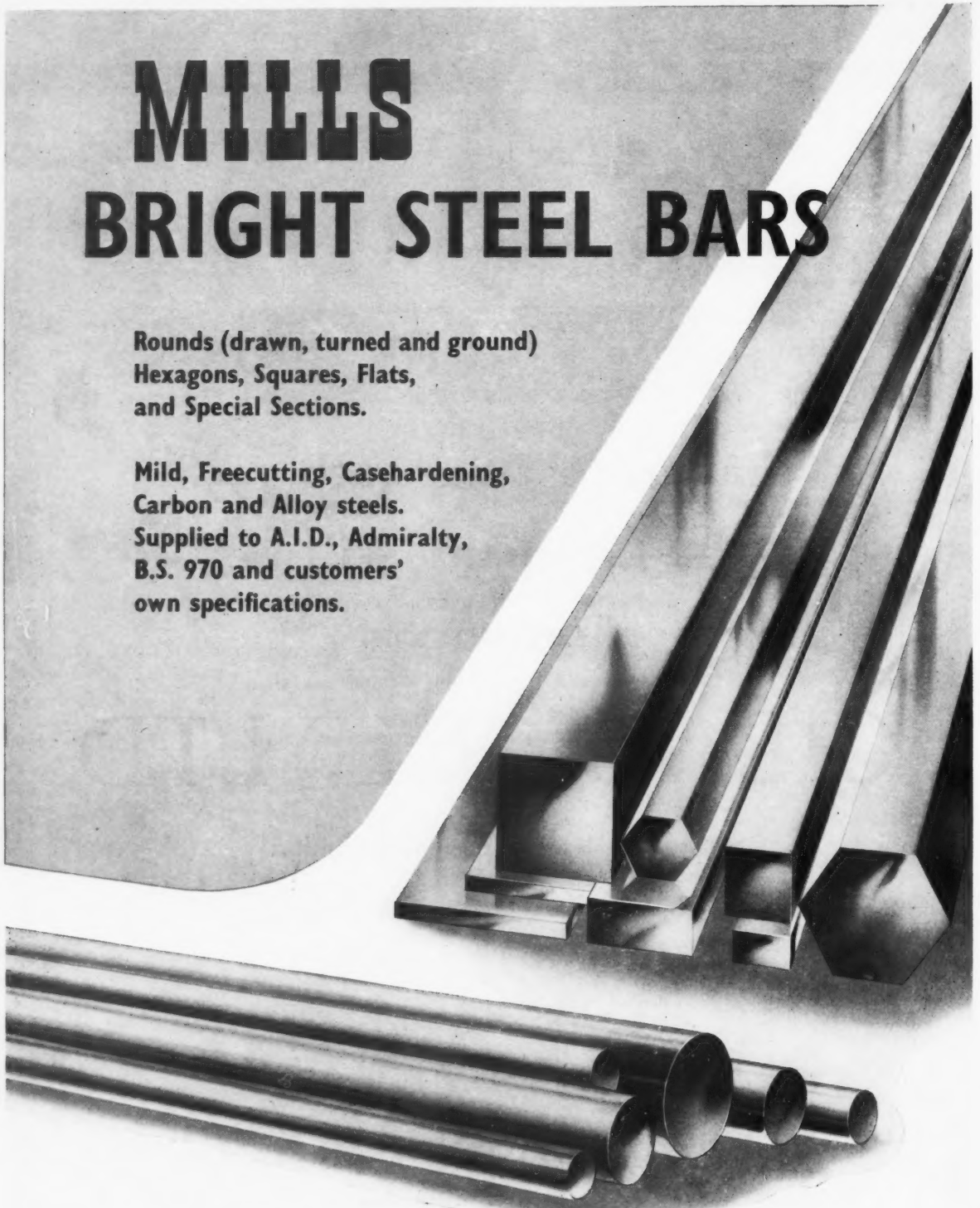
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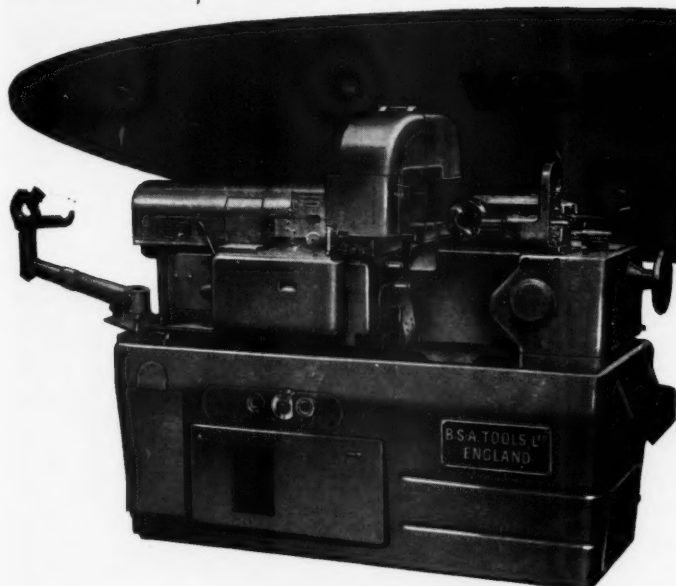


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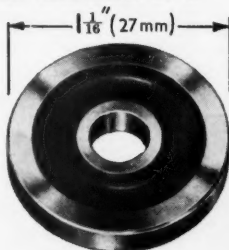




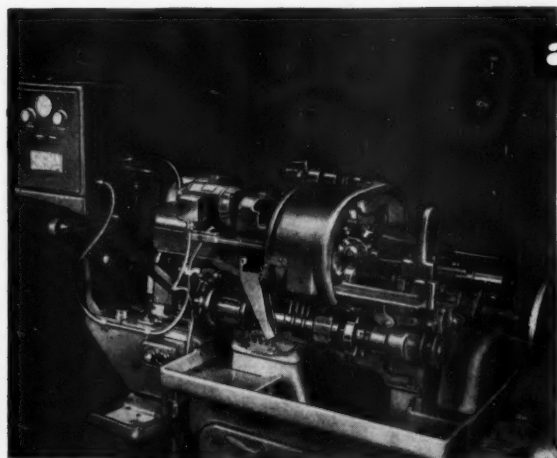
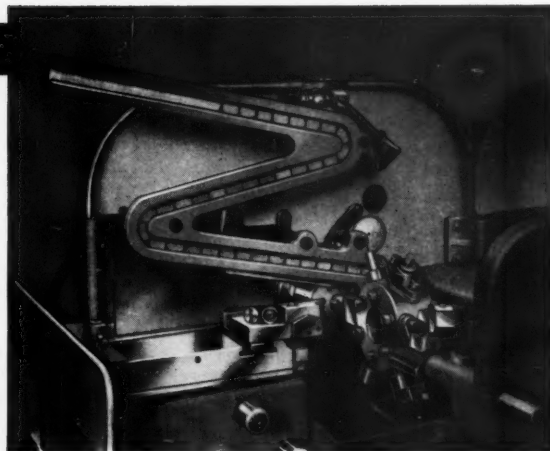
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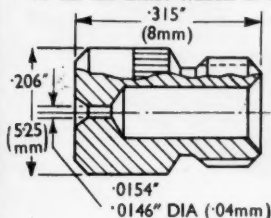


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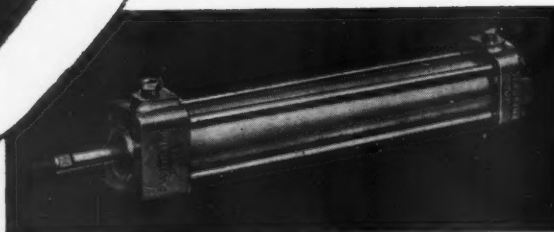
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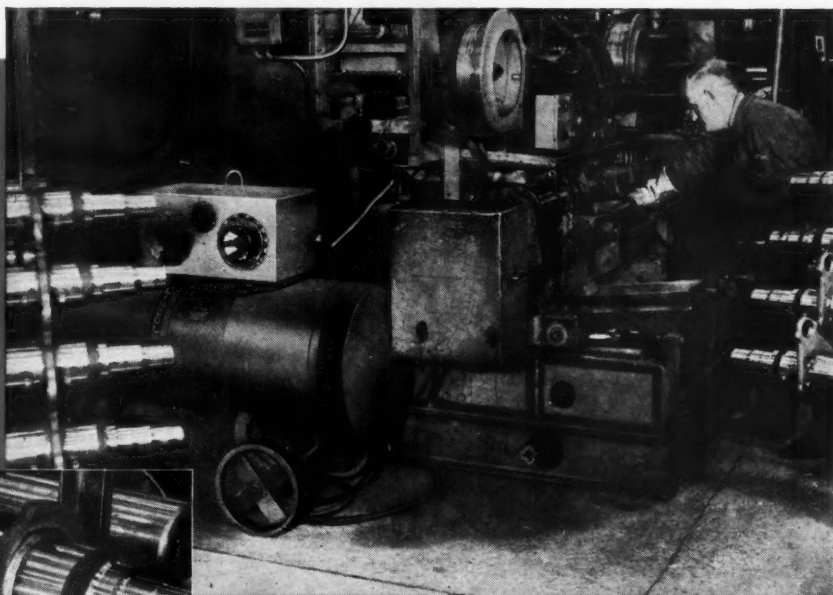
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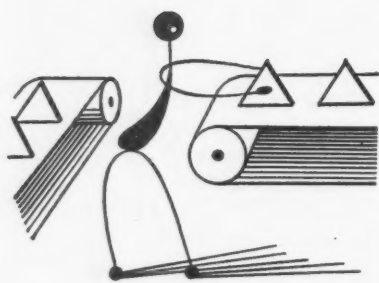
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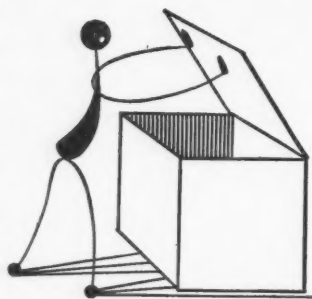
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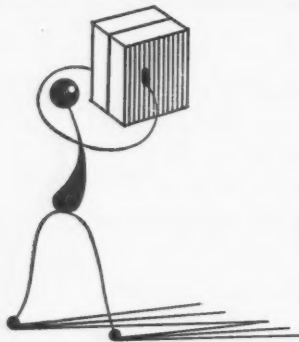
*...transfer...*



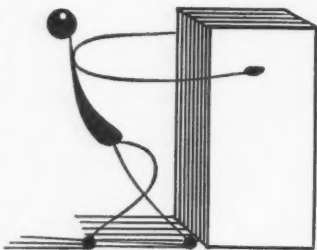
*...open...*



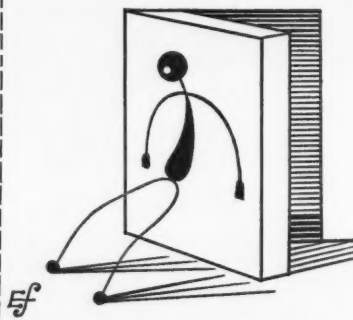
*...bend...*



*...clamp...*



*...pull...*



*...close...*

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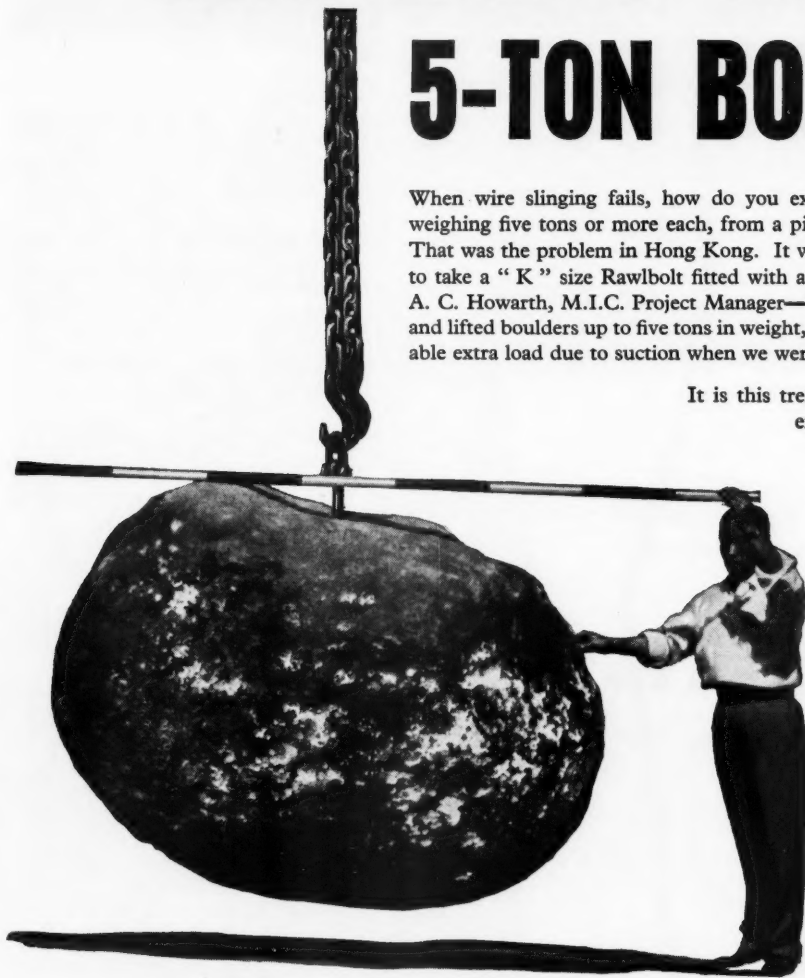
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We are indebted to Messrs. George Wimpey & Co. Ltd., the Building and Civil Engineering Contractors, for the above information. The photograph was kindly provided by Mr. Howarth from the North Point Generating Station, Hong Kong.

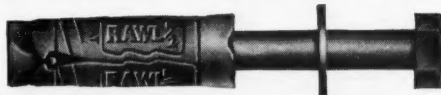
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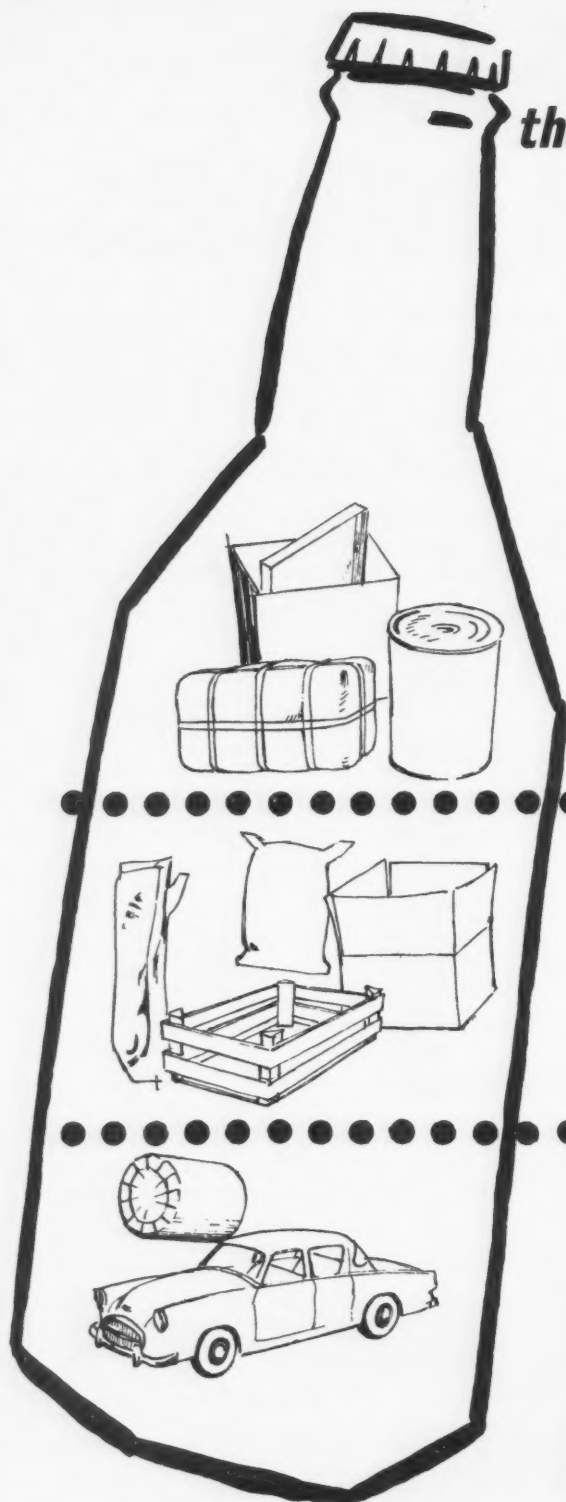
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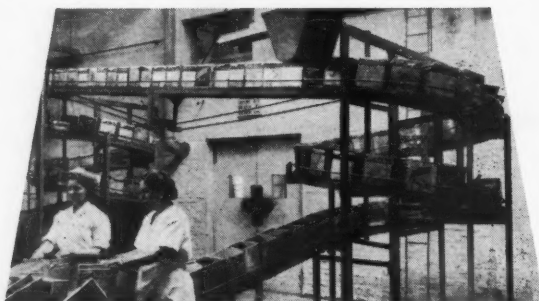
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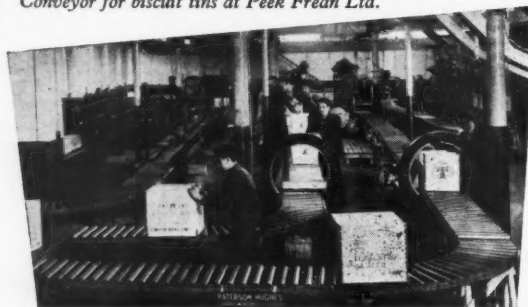


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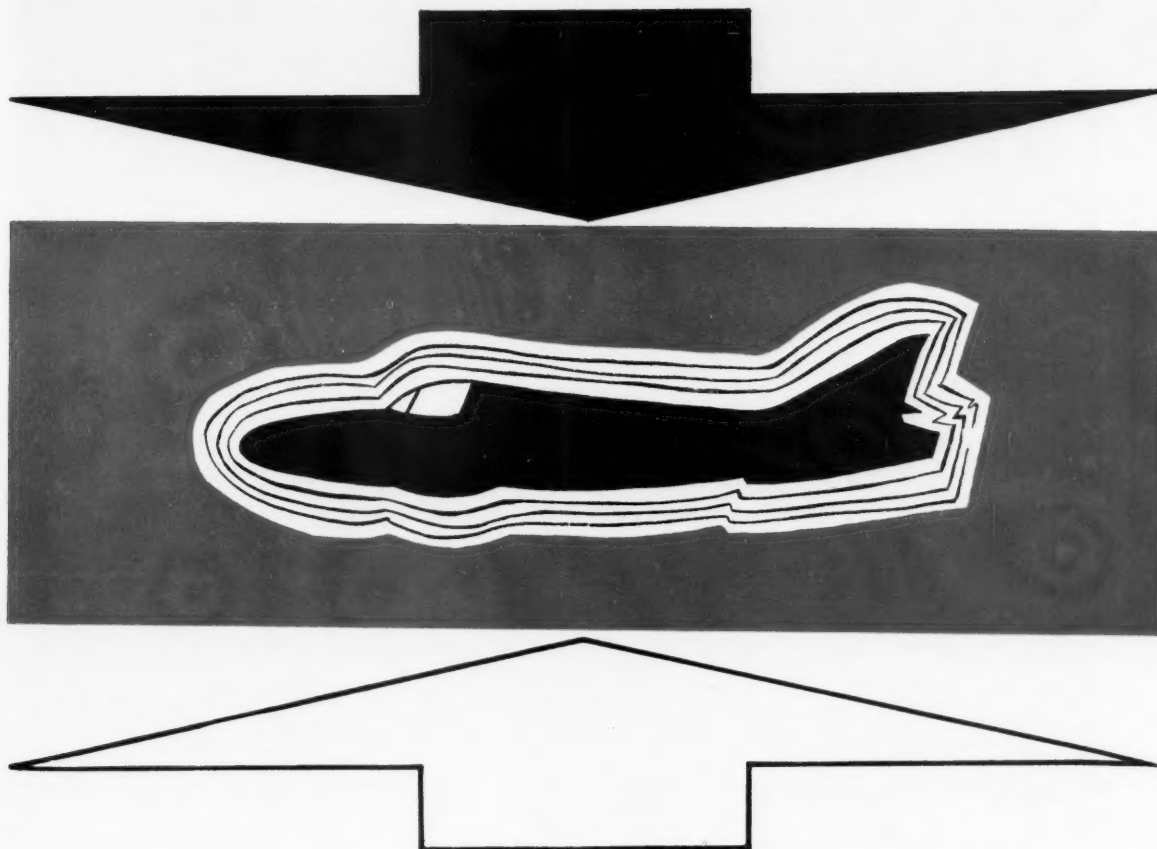
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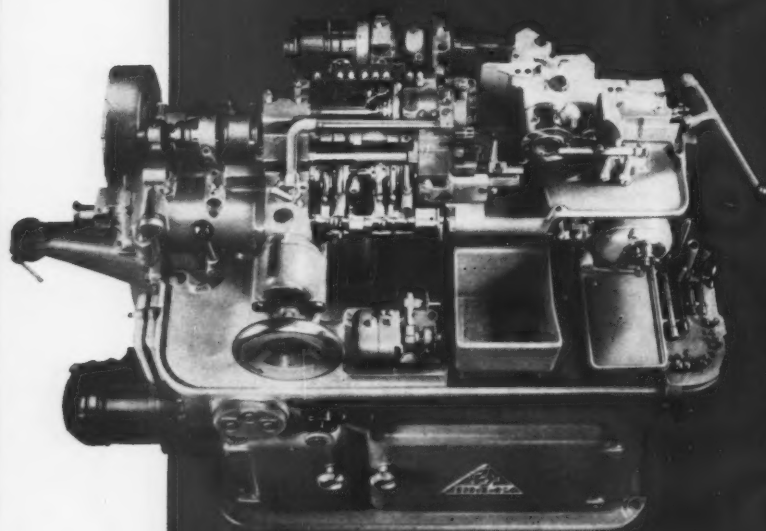


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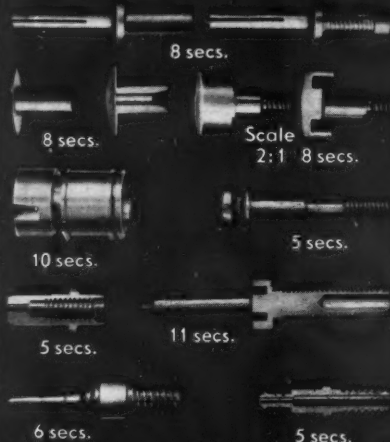
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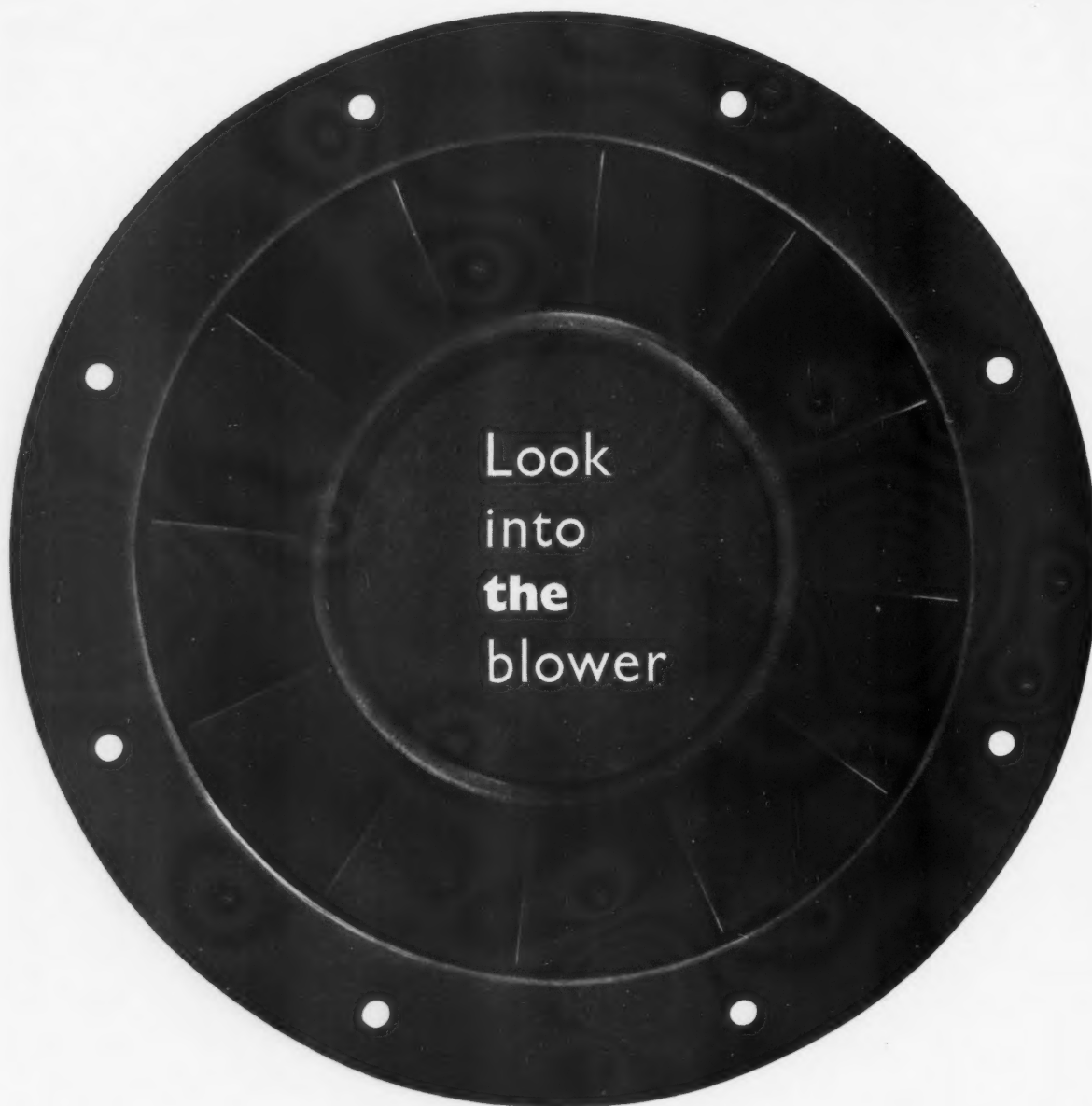


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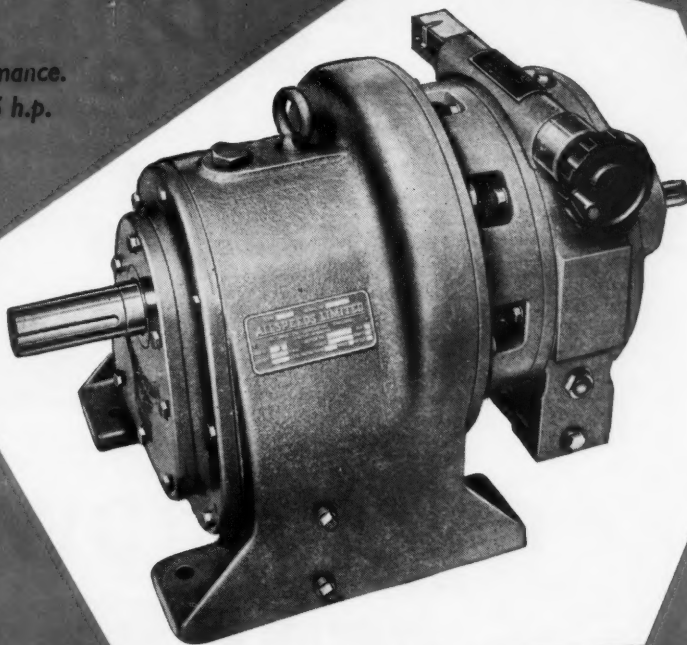
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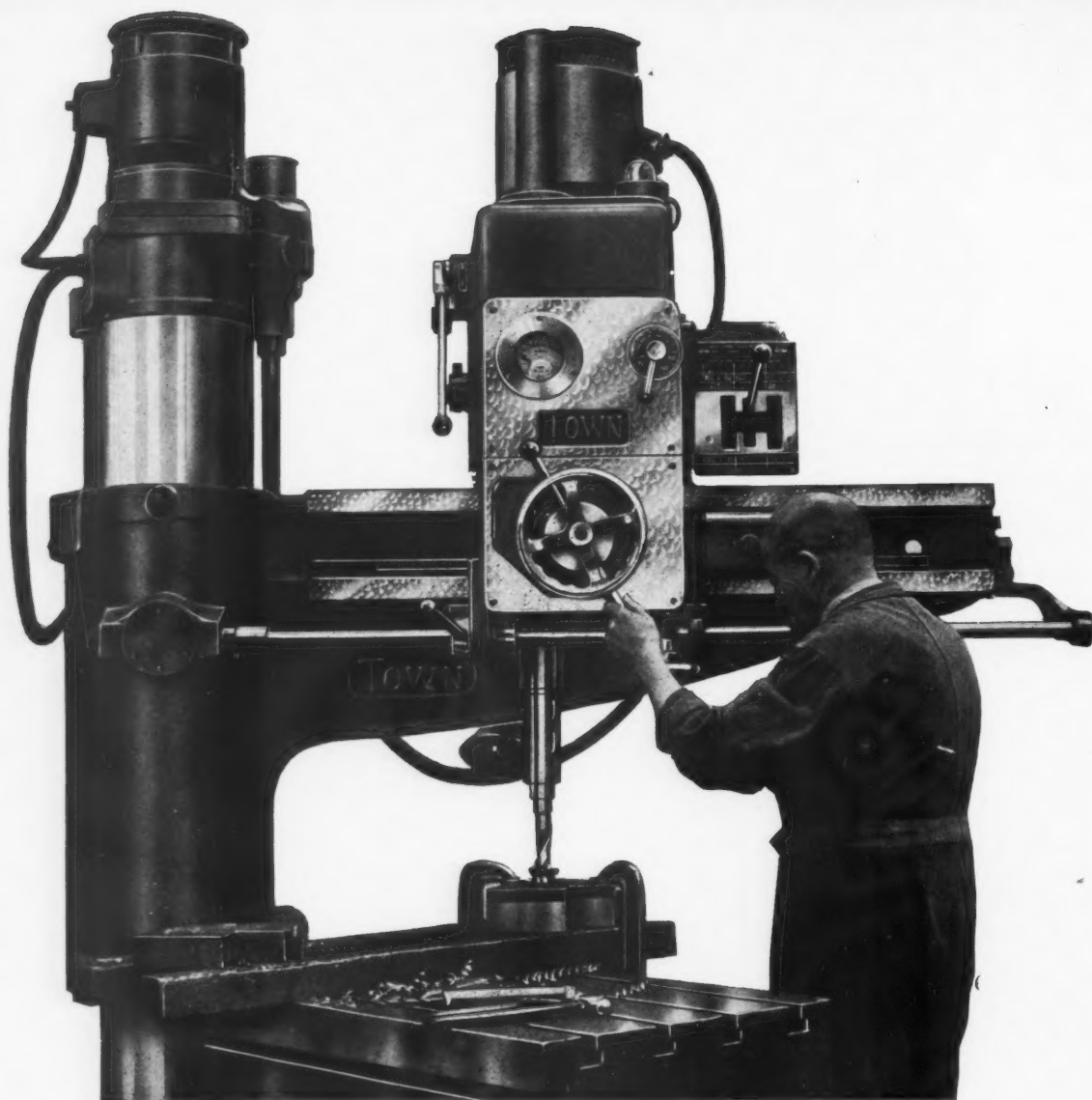
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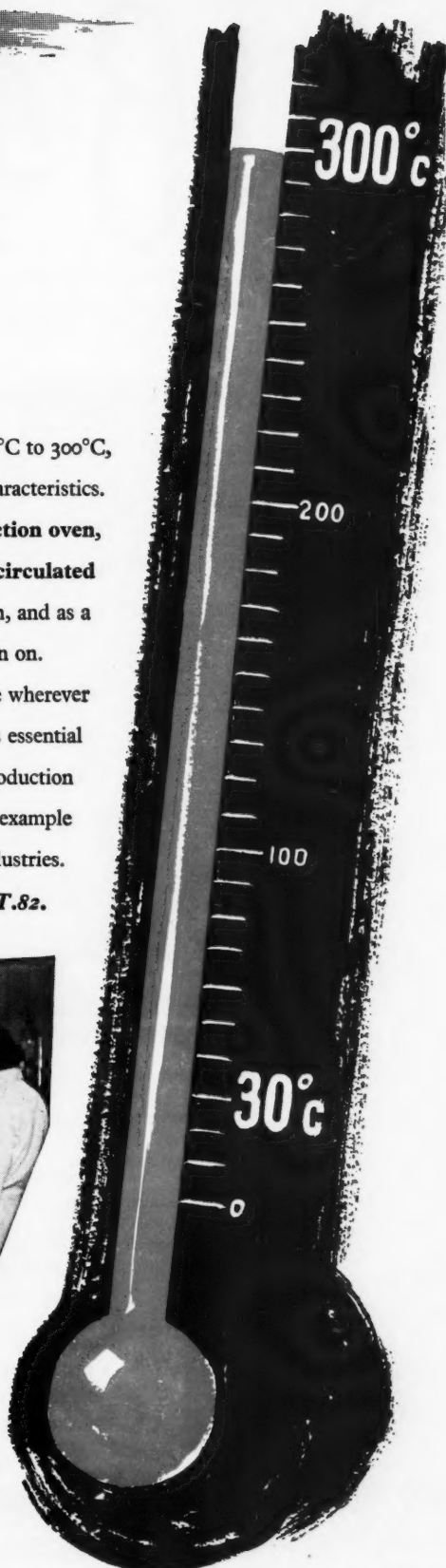


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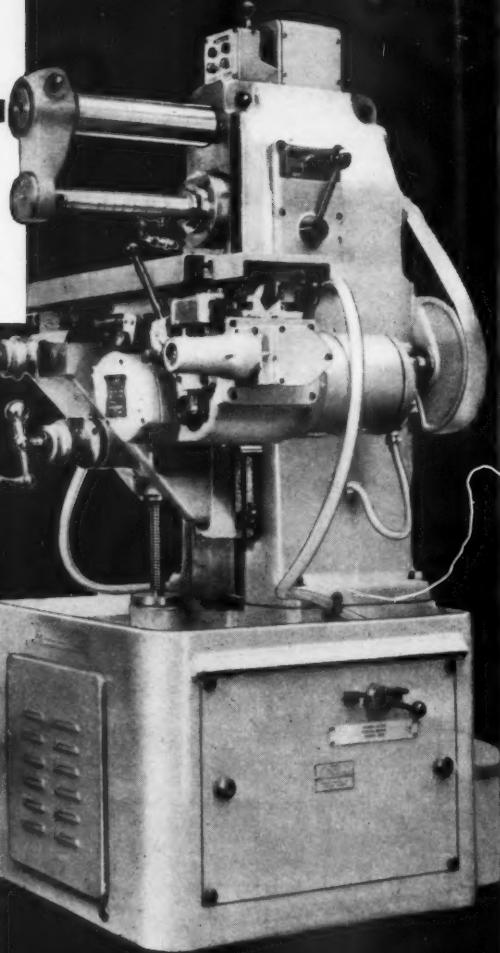
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OF FEED

SPEED  
RANGES

POSSIBLE  
COMBINATIONS

that's  
the  
beauty  
of the

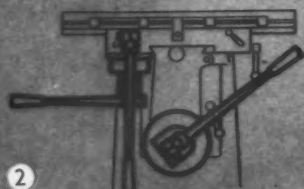
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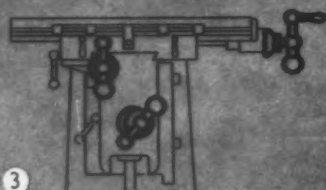
6 With automatic cycle.



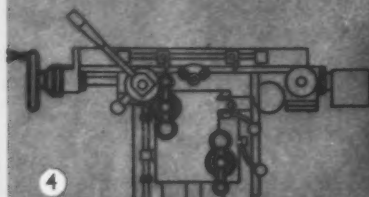
1 Hand Feed—lever, screw, lever.



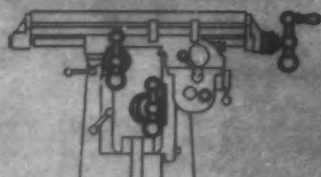
2 Hand Feed—lever, lever, lever.



3 Hand Feed—Screw, screw, screw.



4 Multiform—semi-automatic cycle.



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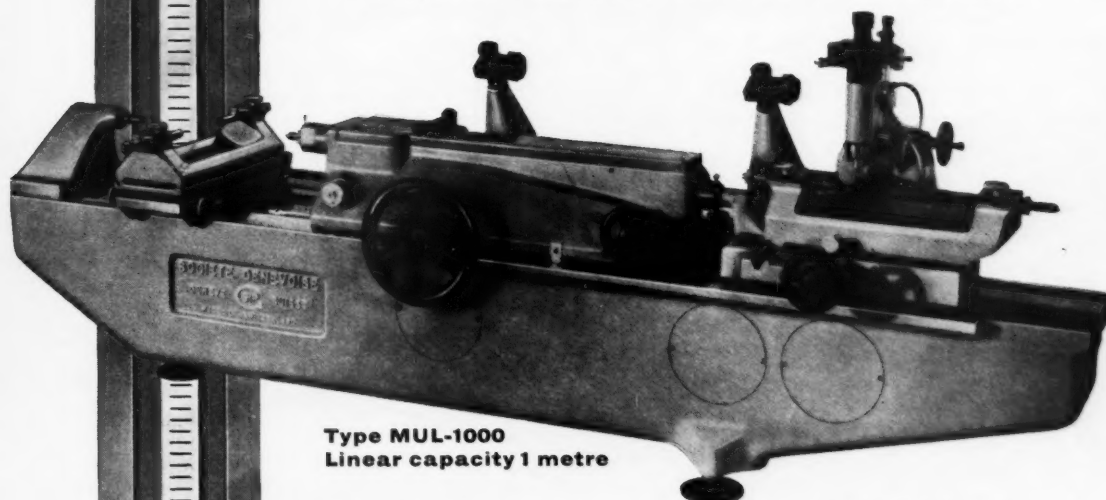
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up to 20"	...	0.00004" .. ..
up to 40"	...	0.00006" .. ..

This machine measures lengths up to 40"; inspects the elements of threads up to 5" in diameter; checks tapers and solids of revolution. It is able to measure in rectangular co-ordinates. It possesses micrometer and goniometric microscopes; readings are easily and speedily taken.

The Universal Measuring Machine is used to measure flat and spherical-ended standards, cylindrical and screw gauges, ring and snap gauges, contour gauges and many standard workpieces. Accessories enable the Machine to be adapted to other requirements.

The MUL-1000 is one of several Measuring Machines in the manufacturing programme of Société Générale d'Instruments de Physique which also includes:

MUL-3000 and MUL-4000 Universal Measuring Machines of 3 and 4 metre linear capacity.

MUL-250 Shop Gauge Measuring Machine.  
MU-214B Three Co-ordinate Universal Measuring Machine.

Detailed information about the scope of these unique machines is available free on request from Société Générale Ltd., Newport Pagnall, Bucks., Telephone: 460-1-2

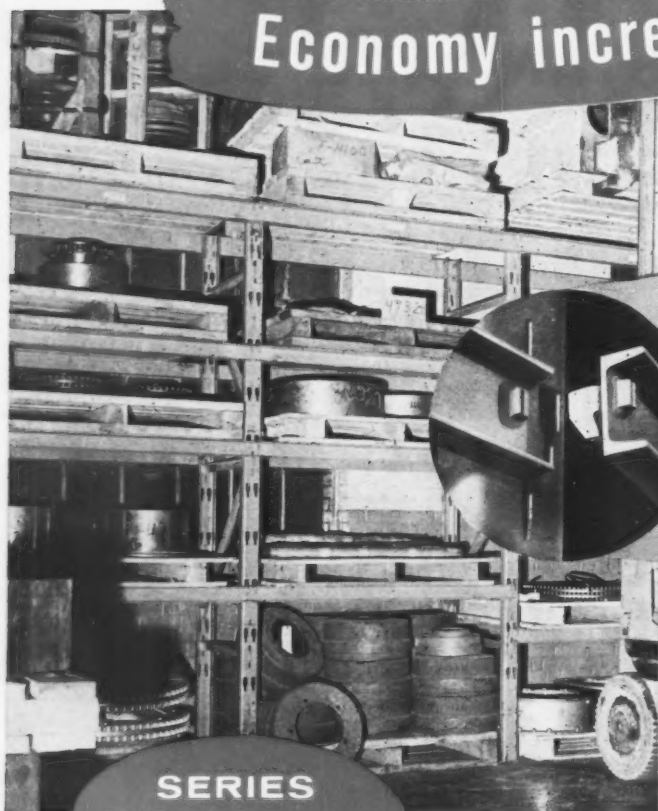
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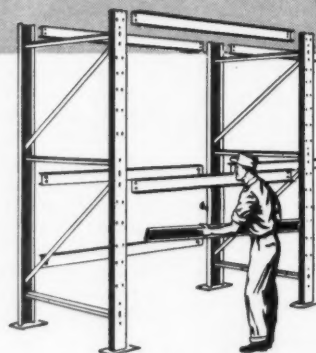
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- 2** excellent heat transfer characteristics thus permitting lower and more uniform operating temperatures to be maintained throughout a winding,
- 3** appreciable reduction in weight for coils maintaining the electrical characteristics of a copper winding, and
- 4** smaller space occupied by the insulating film.

ANODAL insulated wire is at present supplied in sizes within the 16-36 swg range at prices which permit appreciable reduction in wire costs for many applications.

Full particulars are available on request.

★ ANODAL is a registered trade mark.



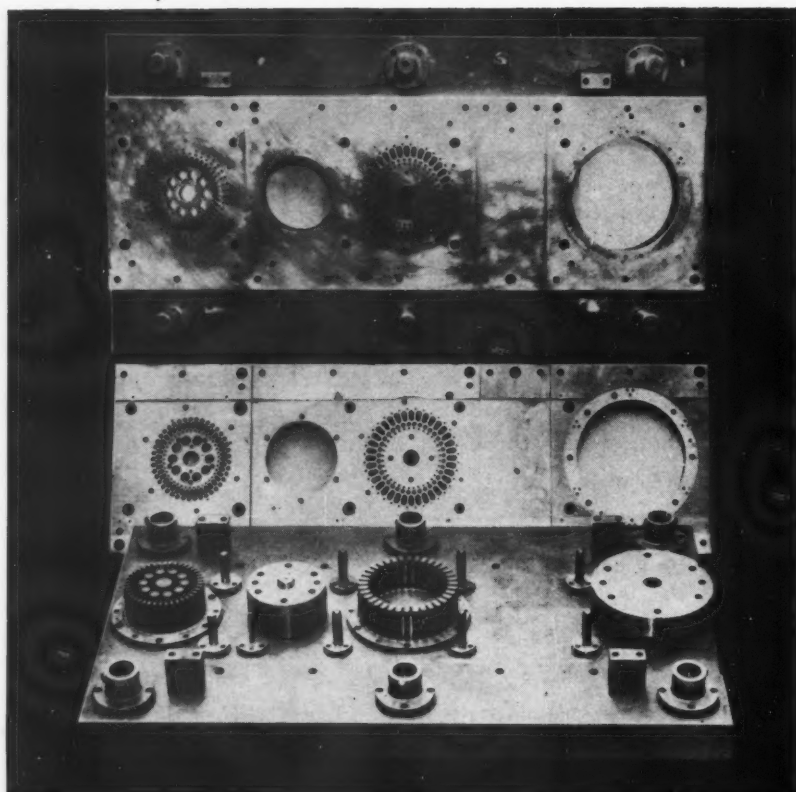
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This die is believed to be the largest of its kind in use in this country. It measures 5 ft. by 2 ft. 6 in., and weighs 3 tons; the material is Edgar Allen 'Double Six' Die Steel. It is used by Brook Motors Ltd. for punching ten H.P. stator and rotor laminations in a complete operation at 80 strokes per minute from electrical quality strip 11 in. wide by 0.020 in. thick. The tool is finished to fine tolerances of 0.0001 in.

About 80,000 laminations are obtained per re-grind of the tool and the life expectation of the die is from 7 to 8 million stampings.

A die of this size, complication and precision reflects great credit upon the Jig and Tool Department of Brook Motors Ltd., where it was made. The use of 'Double Six' steel reflects the confidence of all users who have tried this remarkable Die Steel for important work.

*For full particulars of 'Double Six' and other Edgar Allen Die Steels and their treatment, write for free booklet.*

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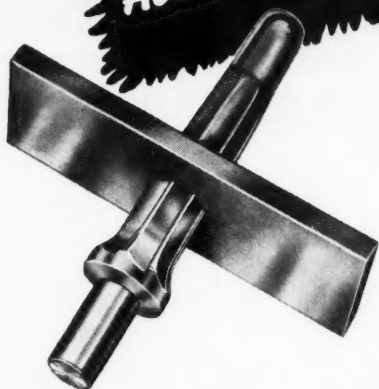
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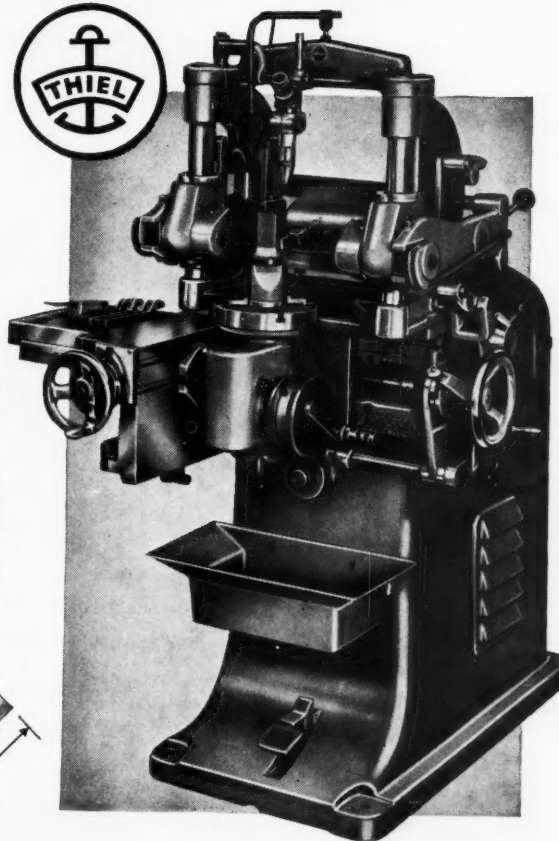
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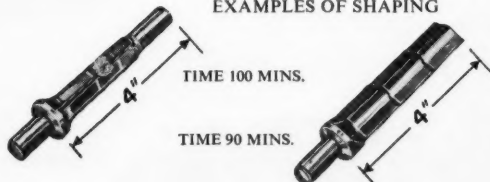


Easily produces stepped electrodes, thus enabling one electrode to be used for both roughing and finishing.

Machining of intricate shapes made easy. Punch and electrode can be made together from one piece of steel, or if copper electrode required, in one operation by previously soldering the copper part on to the steel part.

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EXAMPLES OF SHAPING



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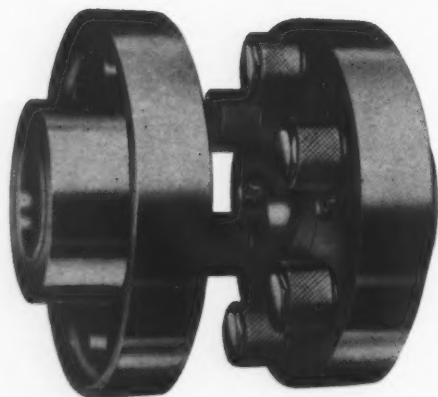
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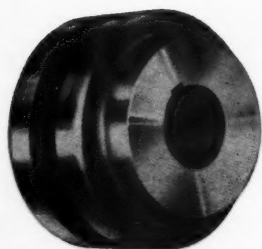


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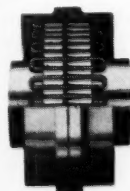
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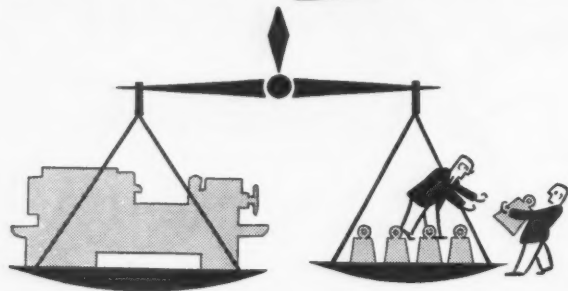
London Office: 5 Charles II Street St. James's SW1

Magnesium Elektron, Inc., New York 20, USA



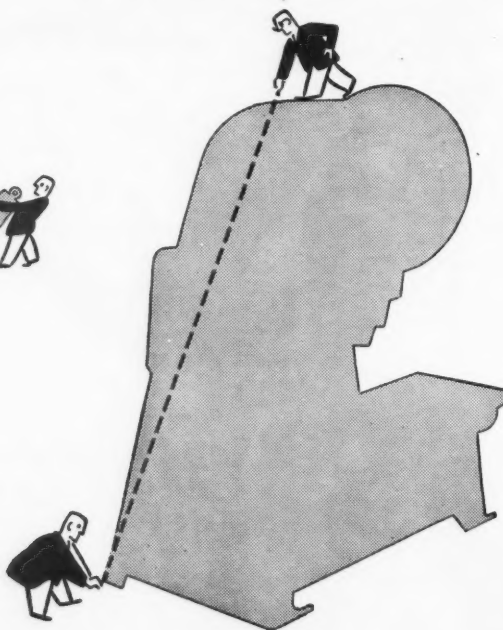
*Prophecy* — a sculpture in magnesium  
for MEL by Winston Clarke

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**BY WEIGHT?**

**BY VOLUME?**

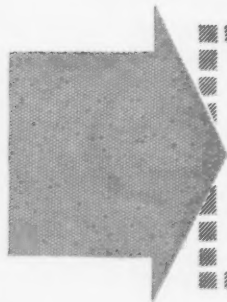


**OR BY HONEST-TO-GOODNESS FITNESS FOR PURPOSE?**

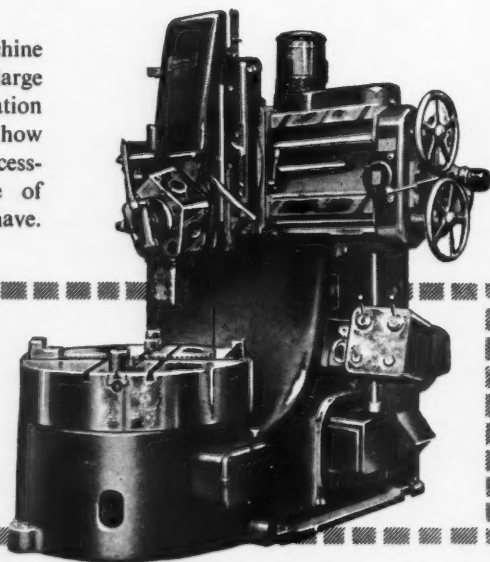
Whichever method you favour you'll find there is no better value in the world, to-day, than Webster and Bennett Boring Mills.

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You can find evidence of their popularity in most machine shops concerned with the boring and turning of medium to large castings and forgings, and if you *can* conduct a short investigation on your own account, ask how long they have used them; how they like the centralised hydraulic control system; or the accessibility of the unit-constructed sub-assemblies and ease of servicing. You'll get the answers we would like you to have.



This is a standard Webster and Bennett Boring and Turning Mill with 48" dia. chuck, admitting jobs of 53" dia., with 35" under the turret and 24" under the cross-slide. Machines can be supplied with Screwcutting, Taper Turning, or Spherical Turning Attachments, or with built-in Electronic Profile Turning Equipment.



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The MULTI-GAUGING CABINET (for checking crankshafts) measures 9 external dimensions and one length check simultaneously. The component is held in pneumatic centres operated by a foot pedal, allowing fast handling. Component tolerances within .00025.

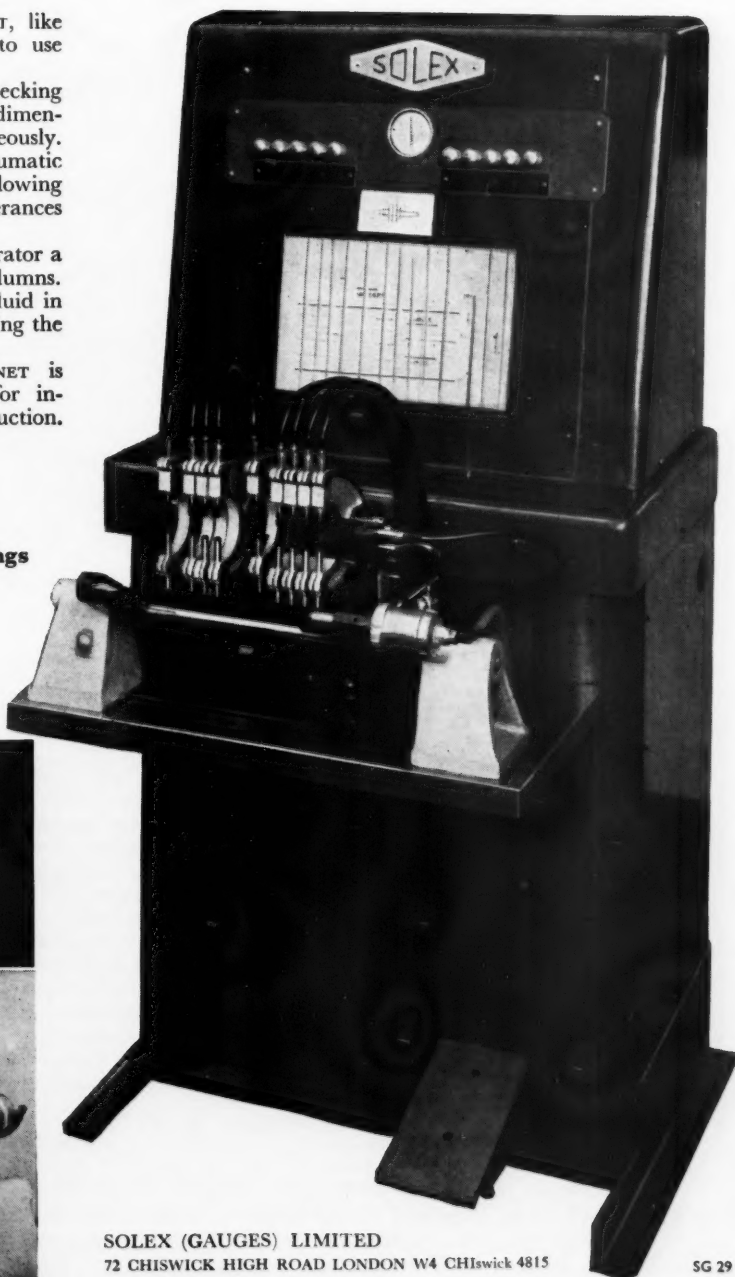
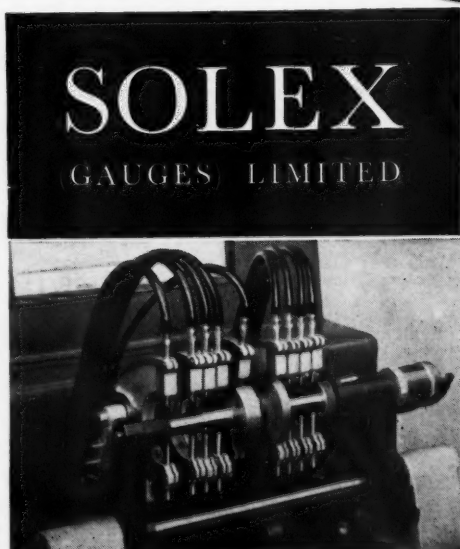
The illustrated panel gives the operator a clear picture of the positions of the columns. An automatic device tops-up the fluid in the air controller, thereby eliminating the daily topping-up usually necessary.

The SOLEX MULTI-GAUGING CABINET is another dependable instrument for increasing quality and rate of production.

**SOLEX have the measure of things**

*Photographs courtesy of*

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"Here's my point, Tom: it pleases the customer, and it saves Vim money. I hear 3M's taping machinery tackles 300 tops a minute, and saves Vim a lot of valuable time.

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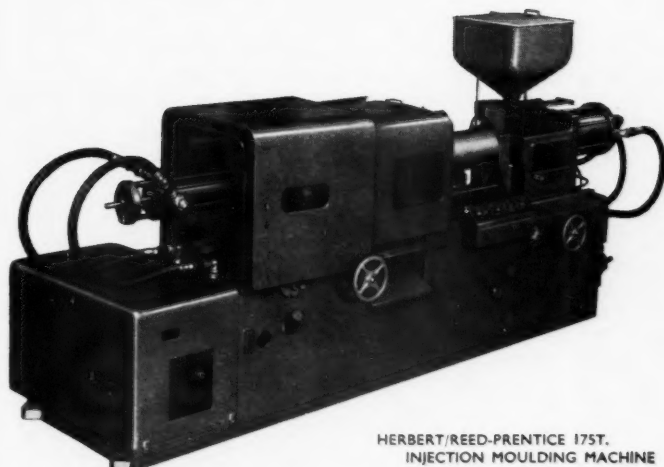
*\*3M's Tape Customer Engineering Department at your service — without charge. Phone HUNter 5522*

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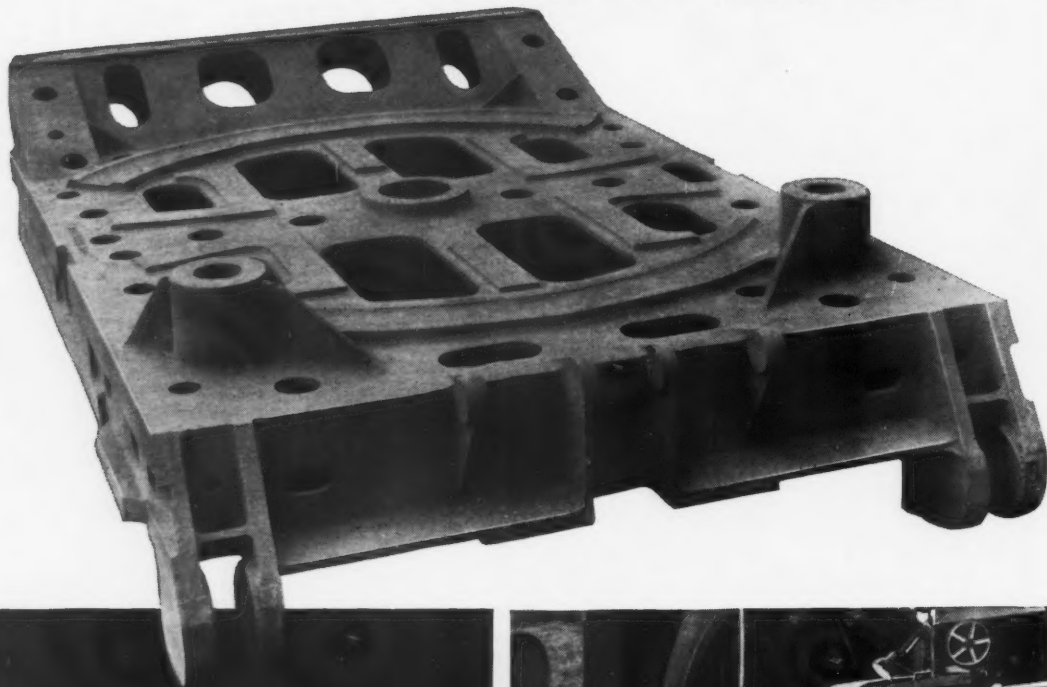
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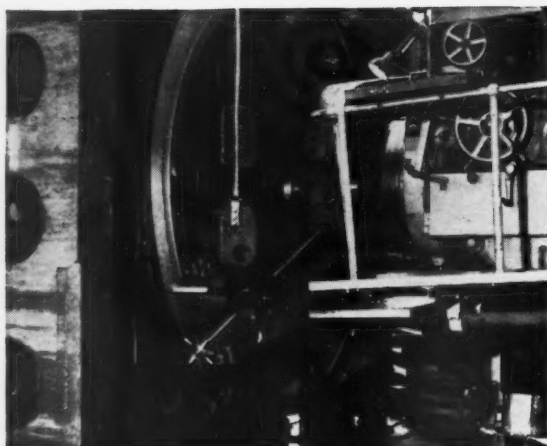
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AD.426

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for an  
important part**



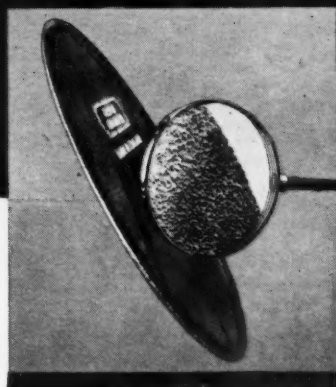
This massive revolving frame is cast in steel for the 150-RB excavator. Weighing 29 tons "as cast" it measures 10 ft. x 15 ft. 6 ins. and is a normal Lloyd production casting. It has to stand up to the severe shock loadings which are developed progressively, as when the 150-RB bites into compacted soil or loose rock that is lifted in one operation. The mould contained 80 cores and there were 21 feed heads. Co-ordinated with the casting was the machining process, a task well within the scope of Lloyds unsurpassed machine shops. The proof of a perfect casting lies in the machining, and it always operates to the advantage of the customer to allow Lloyds to machine the castings they make for him.

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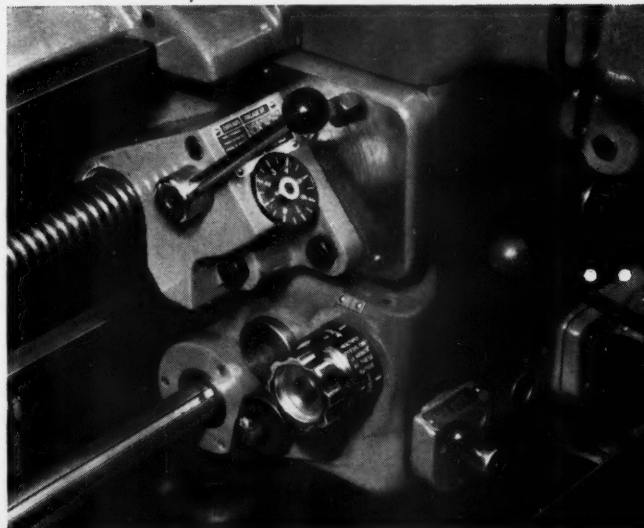
**IF YOU WANT TO GET A MOVE ON**

**Send for the man with the MONORAIL plan**

**BRITISH MonoRail LIMITED**

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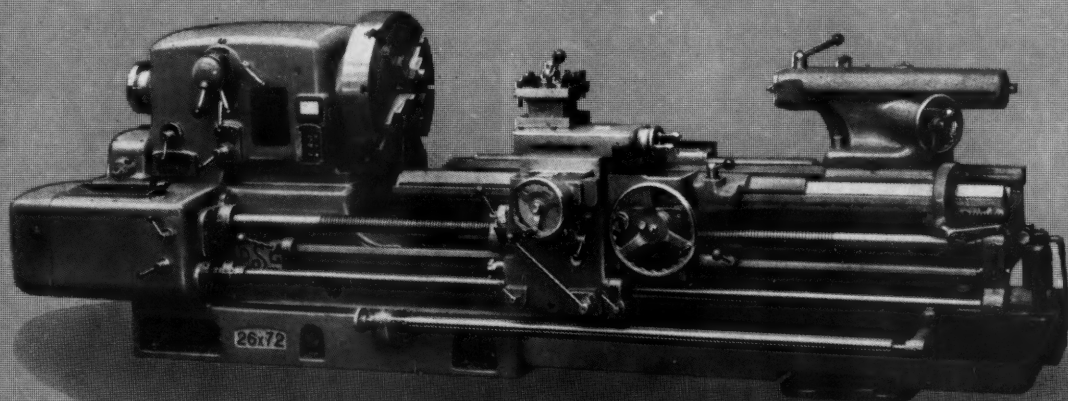


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This was the shape of





# of oil after radiation

Here was a problem of national importance. Lubricants were needed by the nuclear industry for reactor equipment, much of it subjected to radiation. Yet, like human beings, oils and greases were vulnerable to radiation. Oils darkened in colour and became coarse-grained solids (solidification being but one of a tangled skein of problems).

The Shell Group started working on the problems of lubricating under radiation conditions while most nuclear power stations were still on the drawing board. In fact, Shell was the first oil company to develop Atomic Power Lubricants, and the research that went into Shell A.P.L. is characteristic of the way Shell sets about doing things. A team of research workers was assembled

at Shell's Research Centre at Thornton. Series of tests were carried out both in the B.E.P.O. pile at the U.K. Atomic Energy Authority Research Establishment, Harwell, and with Thornton's own Cobalt 60 source of radiation. In 1957, after four years of research, Britain's first range of Atomic Power Lubricants was on the market.

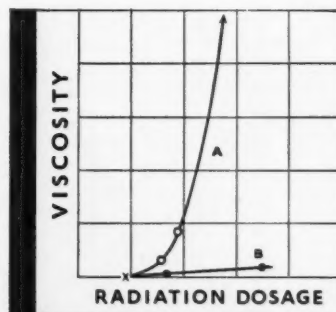
The moral of the A.P.L. story is that Shell research is supremely applicational. The Centre at Thornton is always ready to work with even the most specialised sectors of industry to produce the right oil for the job. If you and your organisation have any major lubrication problems, it will pay you to get in touch with your local distributor of Shell Industrial Lubricants.

## The Research Story

In the hundreds of complex hydrocarbons examined, very different reactions to radiation were observed according to the configuration of the atoms in the molecules. When carbon atoms were arranged in long, straight chains, radiation caused these chains to link up with one another, giving highly complex structures of an entirely different nature from the original material. The first effect of this change was to cause a rapid increase in viscosity, ultimately giving rise to a solid rubber-like product.

For example, a high quality turbine oil conforming to BSS.489 receiving a dosage of  $1.77 \times 10^{18}$  neutrons/cm<sup>2</sup> was changed into an intractable solid—a clear demonstration that radically new lubricants were needed by the nuclear industry.

Shell Atomic Power Lubricants have a molecular structure that has proved itself very resistant to radiation. In fact it will withstand a radiation dosage four million times stronger than that which will kill a man—without any significant change in structure or physical properties.



Relationship between radiation dosage and percentage increase in viscosity, cS at 100°F.

Oil A: high molecular weight long chain hydrocarbon. Oil B: Shell A.P.L. 731.



## ATOMIC POWER LUBRICANTS

another proof of Shell leadership in Lubrication

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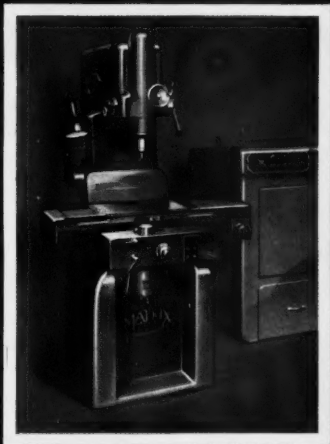


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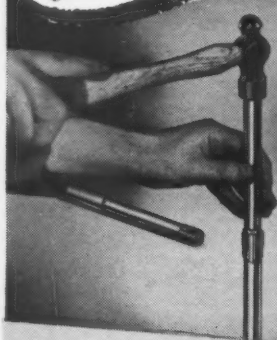
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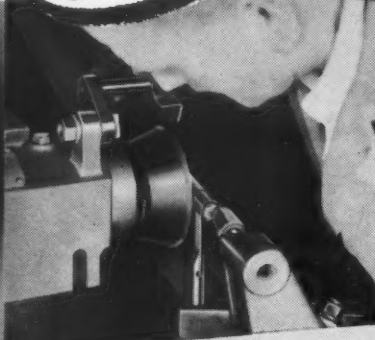
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### EXPANSION REAMERS

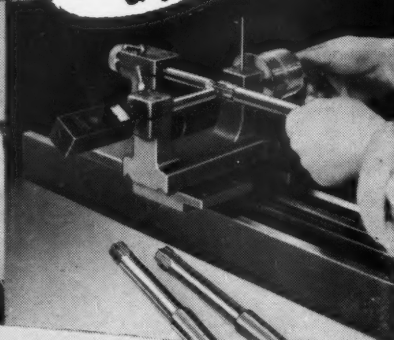
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# Business Financing and The Stock Exchange

by GORDON CUMMINGS

IN recent years, large and increasing sums have been invested in a great deal of capital development ranging from housing to new factories, modernisation of existing plants and retail distribution outlets. Taking the latest National Income and Expenditure estimates, the total gross amount of such investment in the six years 1952 to 1957 was £18,704 million. Annual outlay at current prices rose year by year from £2,411 million in 1952 to £4,050 million last year, to be compared with the average of £3,117 million.

## three main groups

Capital investment falls into three main groups — gross fixed capital formation at home; the value of physical increases in stocks and work in progress; and United Kingdom net investment abroad. The most interesting and significant figures are those of the first and third groups, and the break-down of the first group.

Gross fixed capital formation at home during the past six years totalled no less than £16,380 million, of which, according to the official analysis, £11,665 million was attributable to persons, companies and public corporations; £1,290 million to the Central Government; and £3,425 million to local authorities. Whereas, however, annual outlay by the Government and local authorities varied not very widely from the averages of £215 million and £571 million, respectively, the average of £1,944 million for the first sector went against a fairly steady rise from £1,358 million in 1952 to £2,558 million in 1957.

In its particular way, the third group has shown a more remarkable trend. Despite balance of payments problems, which have called for strong action at times to stop heavy drains on the gold and dollar reserves, this country has continued her traditional rôle of a major overseas investor. In various ways, directly and indirectly, Britain has been investing abroad at the rate of some £200 million a year. Per head of the population, she is in fact the largest overseas investor in the world, with over half the money representing private investment — a higher proportion than in the U.S.A.

## the sources of capital

What are the sources of all these vast sums of capital? First, limited companies and public corporations provide a very large proportion themselves, from the amounts set aside out of trading profits for depreciation and obsolescence and net profits put to reserves after payment of taxation and dividends or interest on capital.

Second, the Central Government and local authorities also meet part of their capital needs out of surplus taxation, rating and other revenue in the case of trading activities; further sums are provided out of depreciation or sinking funds. In other words, part of their tax revenue is diverted to capital projects such as housing, public works and, in the case of the Government, to loans for the expansion and modernisation of the nationalised industries.

Third, the savings of individuals, including the depreciation and profit retentions of unincorporated businesses. To a substantial, and growing, extent a great deal of the savings of individuals finds its way indirectly into capital investment through contributions to pension funds, life assurance premiums, deposits in savings banks, building societies, co-operative societies and other friendly or mutual associations, and trades unions — the surpluses of these bodies are invested in various forms, to a large extent in Government and similar securities; and, in many cases, in the stocks and shares of limited companies.

Although the companies, corporations and Government — national and local — finance much of their capital development from their own "savings", they have to look elsewhere for the balance of their investment funds. This they do largely by tapping the surplus of personal savings, which today represent some 40% of all saving.

Naturally, in our complex society, as this often involves much more than the relatively simple "one-man" operation of borrowing from a bank or individual, or raising a mortgage, there has to be efficient machinery for channelling funds from a multiplicity of sources to the points where it is needed. As with the distribution of most commodities, there has to be a market place where everyone can be brought together speedily and efficiently.

#### **an essential task**

The Capital, or New Issue, market centred in the City of London does this essential task. Although called a "market", this vital part of Britain's financial machinery has no market *place* as such. With many generations of experience on which to draw and unrivalled anywhere for skill, knowledge and initiative, its make-up is diverse and widespread. Participants, each with their essential rôle and some of them with headquarters in the provincial cities, include finance houses, the merchant banks, insurance companies, trust companies, pension funds, British and Commonwealth banks, the Bank of England and, last but not least, the Stock Exchange.

The nature of a capital issue has a direct bearing on the method of operation. For instance, a British Government loan or funding operation is carried through today almost entirely by the Bank of England and the Government Broker, with the Government departments participating as major subscribers — in some instances the entire loan is taken by the departments, which then "let it out" through the Stock Exchange to institutional and other investors, often at rising prices.

Otherwise, although the Bank of England will advise on the terms and timing in the case of local authority, Dominion Government and other gilt-edged issues, the pivotal point is what is called an Issuing House, which may be a finance company specialising in such business, a merchant bank, one of the mining finance houses, a firm of stockbrokers with a new issue department of their own, or, in the case of very large issues, a consortium of several "houses". The Issuing House carries through all the negotiations, advises on the terms and timing, and looks after the routine and sometimes delicate work of setting the machinery in motion. The other participants provide banking, stock market, underwriting and other essential services.

An Issuing House has considerable responsibilities. While its main work in the case of a gilt-edged issue is to arrange underwriting and contribute its experience to the settlement of terms, an issue by a limited company can be a much more complex business. The latter may be an established public company wishing to raise additional capital or to convert an existing issue of loan or preference capital; it may be the issue of capital by one company in exchange for the capital of another

which it is taking over or with which it is amalgamating; or it may be an offer to the public or a marketing of the share or loan capital of a new company or a company whose capital has not previously had a stock market quotation.

Established issuing houses are very proud of their reputations and before they will become associated with any issue they want to be assured of its soundness. If it is a company with which they have already been associated, the preliminaries may not go further than bringing up-to-date the relevant information about the company's profits, assets, prospects and management; the reason for wanting new capital; and deciding the size, form, terms and best time for the operation.

When, however, the proposition concerns a private business about which little, or only general, information is available, much more enquiry and investigation are demanded. As a preliminary, the issuing house will want to know how long the business has been established, its ramifications, whether it is soundly managed, who controls its affairs, if it has a reasonably sure and expanding future, the reasons for turning it into a public company or raising new capital, and that its profits and assets are large enough to make a public issue feasible.

Officially supplied information will be supplemented by enquiries amongst outside sources as to the reputation, trade standing, competitive position and management of the business. Next, experts and principals of the issuing house will get the "feel" of the business and its management by personal examination. Independent accountants then report on the profits over a lengthy period of years, recent balance sheets, the basis of valuing the assets and the adequacy of financial, stock, costing and other controls.

When all this information has been digested, the issuing house can then make its proposals as to the form and terms on which a successful issue might be made. Economic and stock market conditions at the time have a direct bearing here. For instance, apart from factors such as the size and nature of the operation and the type of business, current conditions and public appetite for particular types of securities play a vital part in deciding whether the offer should be ordinary shares, preference shares, debentures or, a growing popular form, loan stock which can be converted into ordinary shares on defined terms.

Apart from "rights" or other offers made only to shareholders of public companies, the mode of the operation has next to be settled. It can be a public issue on stated terms, with the issuing house making all the arrangements and underwriting it. Alternatively, it may be an "Offer for Sale", with the issuing house or some other party buying the securities offered at stated prices and reselling to the public at higher prices, the difference covering expenses and profit.

A third method, usually adopted where the amount involved is relatively small, is a "placing". The issuing house "places" blocks of stock at fixed prices with finance houses, insurance companies, pension funds, trust companies, brokers and other connections. Unless there is some reason to the contrary, permission to deal in the stock is sought from the Council of the Stock Exchange and a market made. A fourth method, generally limited to comparatively small companies or cases where large holdings have to be dispersed to meet death duties or for family reasons, is the "introduction" to the stock market of part of the company's capital.

### **publishing the prospectus**

With the exception of issues limited to existing shareholders, where a letter setting out the reasons for the operation and giving information as to underwriting, relevant contracts and so on is generally adequate to meet legal and other requirements, a prospectus or similar statement has to be published. As the "shop window", this is a most important document and, rightly, the issuing house pays particular and careful attention to its drafting.

Before looking at this side of the operation, it should be pointed out that what can be a very difficult and shifting hurdle has to be surmounted first. Today a company which seeks to raise new capital exceeding £10,000 must first obtain Treasury permission. It must supply to the Capital Issues Committee — who act as the Treasury's advisor — a great deal of information about the nature of the company's business and the terms and reasons for wanting to raise new money.

Though it may be difficult for the outsider to understand the bases on which the C.I.C. formulates its opinions, the qualifying requirement is that the issue should be in the national interests.

The Companies Act, 1948, lays down the information which must be given in a prospectus. It is extensive and thorough. Details of the company's capital and the rights attaching to various issues . . . the extent and terms of the offer . . . the names and addresses of the directors and other officials, the auditors, bankers, brokers and the issuing house . . . the nature of the business and its history . . . recent profits and the basis of calculation . . . the assets and liabilities . . . the reasons for the issue . . . the directors' view of prospects . . . the net proceeds of the issue . . . underwriting and other contracts . . . relevant articles of association such as directors' qualifying shareholding . . . professional valuations and reports . . . these are some of the facts which must be given.

While the prospectus — or in the case of a placing or introduction, the "statement", which is its equivalent — is in the draft stage, the Stock Exchange comes well into the picture. First, the brokers to the issue are advising on important matters such as market conditions and terms. Second, the Council of the London Stock Exchange has to have its own information requirements satisfactorily met, and these are even more searching than those laid down by the law.

In addition to requiring copies of all relevant reports and contracts, the Stock Exchange, which delegates this valuable work to its Share and Loan Department, wants to know a great deal about the directors, officials and others associated with the company and the issuing house. With nothing taken for granted, it has its own records and sources of information from which to check the standing and qualifications of all the people concerned. Close liaison also is maintained with Scotland Yard's Fraud Squad and with the various provincial stock exchanges.

Through the brokers to the issue, the Share and Loan Department may ask for further information or suggest changes designed to give clearer or fuller information to intending investors. While not directly concerned with the prospectus, the directors of the company must also undertake, after a quotation has been granted, to notify the Stock Exchange of future dividend and profit figures and other information as it becomes available.

#### **underwriting**

Another important part of the operation often handled by the brokers is the underwriting of the issue. As underwriting is the guarantee which ensures that whatever the public response the offer will be fully subscribed, it must be placed in financially responsible quarters such as with insurance companies, pension funds, investment trusts, finance houses, merchant bankers, members of the Stock Exchange and carefully selected individuals.

Underwriters, or sub-underwriters as they are often called, are paid commission for their "guarantee". Depending on the nature of the issue, commission may range from as little as  $\frac{3}{4}\%$  on a first-class debenture stock to  $2\frac{1}{2}\%$  or more on the price of a share offer. Although underwriting may appear to be "money for jam" when an issue is over-subscribed and there is no liability, it can be the very reverse when it is under-subscribed. A political, international or economic crisis, or other adverse development flaring up unexpectedly between completion of the final arrangements and the opening of the subscription lists, can turn a certainty into a serious failure.

The company still gets its money; but the underwriters shoulder the burden. And as some recent very large issues have shown, the burden can be substantial and call for long, careful "nursing" before the underwriters get back the capital they have to lock up — sometimes at a heavy loss. For instance, not so long ago they were left with a very large proportion of a £29,000,000 issue of ordinary shares and loan stocks by Vickers, the large shipbuilding, aircraft and engineering group, while in April they had to take up 68% of a £20,000,000 New Zealand Government loan.



After an issue is completed and the Council has granted the quotation which is the prerequisite of dealings, the Stock Exchange carries on a further major and continuing part of the process. It provides the market where buyers and sellers are swiftly brought together at fair prices. Equally, its broker members advise their client on investment and look after the intricate routine work of transferring the ownership of securities.

A few facts show the measure of the service to national and international development provided by the London Stock Exchange, which, despite the hampering limitations imposed by the War and its aftermath, is still the world's greatest international security market.

The nominal amount of almost 10,000 different securities officially quoted is upwards of £30,000 million; and the market value is substantially higher. Varying in amount from a few thousand pounds to many hundreds of millions of pounds, the individual issues cover a kaleidoscopic field from Government, local authority, nationalised industry and other gilt-edged stocks, accounting for more than two-thirds of the nominal total, to the stocks and shares of a great variety of industrial, trading and other companies; giant international oil concerns; bank, insurance, financial and shipping companies; breweries and distilleries; tea and rubber plantations; gold, copper, tin and other mines; and other enterprise in Britain or spread over the free world.

The list is constantly changing as new securities are issued or old stocks are redeemed or converted. Again, the changes are varied. Some of the newcomers represent the raising of new money in ways already described. Others are securities issued for assets taken over by one company from another, or an amalgamation. And others cover the capitalisation of reserve funds by the distribution of additional shares to shareholders.

The extent of the annual additions, together with the amounts of "new money" subscribed through the medium of the Stock Exchange, is shown by the following table which summarises the totals under the two general headings of gilt-edged and foreign Government loans; and securities issued by the companies.

#### QUOTATIONS GRANTED BY THE LONDON STOCK EXCHANGE

<i>Year to March 24</i>	<i>National Amount — All Applications</i>			<i>Cash Subscriptions</i>		
	<i>Total</i>	<i>Gilt-edged, etc.</i>	<i>Companies</i>	<i>Total</i>	<i>Gilt-edged, etc.</i>	<i>Companies</i>
	£'000	£'000	£'000	£'000	£'000	£'000
1950	1,321,927	1,068,948	252,979	194,536	77,142	117,394
1951	1,723,607	1,439,907	283,700	730,310	549,968	180,342
1952	1,534,027	1,193,456	340,571	1,298,007	1,108,445	189,562
1953	1,922,423	1,542,961	379,462	792,441	677,874	114,567
1954	2,717,148	2,189,656	527,492	1,035,631	834,235	201,396
1955	2,850,930	1,914,868	936,062	766,137	493,463	272,674
1956	2,087,712	1,388,831	699,831	1,257,407	925,634	331,773
1957	2,054,381	1,317,067	737,314	824,470	539,714	284,756

Visits to the Stock Exchange, including a lecture of about an hour's duration, can be arranged to take place from Mondays to Fridays. Members of the Institution who would be interested in making up a party for this purpose are invited to communicate with:

THE SECRETARY, 10 CHESTERFIELD STREET, LONDON, W.1.

# THE FABRICATION OF PLASTICS

by Dr. V. E. YARSLEY,

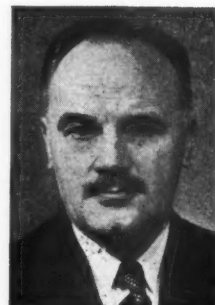
M.Sc., D.Sc.Tech.(Zurich), F.R.I.C., F.P.I., M.I.Chem.E.

*Dr. Yarsley, who is founder and Managing Director of Dr. V. E. Yarsley (Research Laboratories) Ltd., and Dr. V. E. Yarsley (Plastics Testing Laboratories) Ltd., was educated at Queen Mary's Grammar School, Walsall, and Birmingham University, where he graduated in the Honours School of Chemistry, and later Master of Science. He was awarded a Fellowship by the Salters' Institute of Industrial Chemistry, which he held at the Eidgenössische Technische Hochschule, Zürich, where he graduated D.Sc.(Tech.) in 1927.*

*After several years in industry in the manufacture of cellulose acetate and photographic base film, Dr. Yarsley commenced to practise as an independent consultant in 1931, specialising in cellulose ester plastics. This practice expanded along the lines of consultancy and sponsored research and development in high polymers and related materials; it was converted into a limited Company in 1951, and now has a staff of over 100.*

*Dr. Yarsley has been connected with the plastics industry for 32 years, and is Vice-Chairman of the Trustees of the Plastics Industry Education Fund. He was President of the Plastics Institute, 1953-1955; Chairman of the Education Committee of the Plastics Institute, 1935-1955; and Chairman of the Plastics and Polymer Group of the Society of Chemical Industry, 1938-1940.*

*He also serves on the Board of Studies in Technologies other than Engineering of the National Council for Technological Awards; the National Advisory Council for Education in Industry and Commerce; and on the Board of Governors of the National College of Rubber Technology, Chelsea College of Science and Technology, and Kingston Technical College.*



## 1. INTRODUCTION

### 1.1. Terms of reference and definition

When the Chairman of your Papers Committee invited me to address you on the subject of the Fabrication of Plastics, he informed me that it was a condition of this Memorial Lecture to Colonel George Bray that the subject chosen should be one not traditionally associated with engineering. I think that the limitative word is 'traditionally', since I am sure that had this limit not been applied, then the subject of plastics would not have been acceptable, as I am quite sure that there are few branches of technology which are today more closely associated with engineering than are plastics and, as I hope I shall show, this association is becoming closer as the years go by. It was for this reason that I felt more than the usual responsibility of a lecturer, since I have to speak not only for and about industry, but for a large number of related industries which have plastics as a common factor. Having such a wide field to cover I was careful at the outset to make sure that I was accurately interpreting my terms of

reference, since the term 'plastics' may refer to polymers as they leave the chemical factory, raw materials as they go into industry, and the finished products as they enter into almost every phase of our daily life.

The Oxford Dictionary defines fabrication: "to make anything that requires skill; to construct; to manufacture". Quite clearly you would not be interested in the manufacture of the plastics themselves, so I decided that my survey must be confined to the manufacture of the finished plastics product, without which our modern civilisation could not carry on. I propose, therefore, to give a very brief documentary of all the major methods whereby plastics are fashioned into a useful end-product, and I shall cover plastics in the broadest textbook sense as materials which at some stage in their history are capable of flow. I propose to consider not only the production of moulded and shaped units, but also of sheets, films and protective coating surfaces. I do not propose to include the fabrication of plastics in the form of minute endless rods which we refer to more usually as man-made fibres but, as you will see later, some of the processes I shall describe are similar

in principle to those used in fibre manufacture; the differences, if any really do exist, are mainly of degree.

## 1.2. The background of plastics

Before launching into my documentary, I think it will be helpful if I give you a little of the background to the vast industries which are today associated with plastics in one form or another. May I remind you at the outset that plastics are chemicals, and as Dr. Warboys once said, they are fundamentally chemicals which are used for their physical properties. The production of the raw plastics is thus a logical part of the chemical industry, and just as certain as it was once that the initiative and enterprise of the chemical industry gave birth to plastics, so today the increasing importance of plastics is extending the frontiers of chemistry and chemical industry beyond the wildest dreams of the pioneers. As we know it today, the plastics industry is relatively young, although we are soon approaching the centenary of what has aptly been styled the "grand-daddy of 'em all", celluloid, and last year saw the half-century of the pioneer work of Baekeland, which was destined to change the classical concept of organic chemistry, and found industrial use for the 'in-between products', the sticky masses which had been so long rejected by organic chemists as being neither pure liquids nor truly crystalline. Suggesting the use of these materials to his Board of Directors, Baekeland is reported as saying that they could find possible use in 27 different industries. Today, it would certainly be difficult to find 27 industries the world over in which one or other of the vast family of plastics is not used.

Like the products based on natural materials, such as cellulose and casein, these products of chemical synthesis were at first regarded as isolated compositions having no definite family relationship, and having some vague possibility of meeting isolated needs, failing the availability of the conventional materials of construction, wood, metals, and ceramics. For many years after the study of polymeric materials became really serious, following World War I, it is evident from the literature and from one's personal contact with the field, that very few people recognised that the celluloid of Parkes and Hyatt, the casein of Adolf Spittler, the phenol formaldehyde condensation products of Baekeland, and the urea formaldehyde products of Pollak, had any significant common factor. This was recognised in the 20's, and during this period for the first time the word 'plastics' began to appear in technological indexes. It was not unnatural that once the basic principle was recognised, what may well be described as the Baekeland cult soon caught on, and the production of resin-like materials or synthetic "resinoids", as they were widely called, became a popular chemical hobby. This was the day of empirical thinking and even more empirical production, the days of what I would call "cook-it-and-see", and the degree of uncertainty of the time is, I think, amply shown in the handbill put out by the

Borough Polytechnic, London, in 1930, advertising what I believe I can say was the world's first course of plastics technology as a course of lectures on "Synthetic Resins, Moulding Powders and Plastic Materials".

Empirical thought and action was not without its reward, and in spite of many dismal failures on the production scale and the sad end to many dreams of quick and rich manufacturing projects, solid progress was made in the inter-War period. The appreciation that these plastics materials, both natural and purely synthetic, had the common factor of a long chain structure, resulted in the extended search for materials having a giant molecule (by comparison with the small and precise molecules of inorganic compounds). This, in turn, following the work of Carothers and the Du Pont school on the polyamides, showed that the chains could be "tailored" to give products with predictable properties, and indeed that the physical properties of the end-products could be changed at will by the in-building of certain chemical groupings.

The whole picture was changed by the advent of World War II, which ushered in a period when the conventional materials of construction were consumed at an unprecedented rate by all the belligerent nations. Not only was the need for more materials, but materials which had new and quite revolutionary properties, materials such as polythene, for example, which alone could, and did, make radar possible. Prior to the War plastics, if anything at all, had been in the nature of a disembodied spirit; the War gave it the body corporate and laid the foundations for new and in some cases quite surprising advances, so that the chemical industries of the world turned their attention from explosives, dye-stuffs, and pharmaceuticals to the materials of giant molecules soon to be known as high-polymers. New names crept into our technical dictionaries, which indicated that many units of vinyl, styrene or ethylene had been built into one in polyvinyl, polystyrene or polyethylene, and the engineers were not a little puzzled by chemists' 'poly' jargon.

As may be imagined, this was not a period of unmixed joy for either the maker or user of plastics. Indeed the post-War years, particularly in this country, constituted what may be the darkest days in the history of the new industry. What actually happened was that we were trying to run before we could walk and in many cases with half-knowledge of the processes involved, and frequently with inferior raw materials (and these in short supply). Products of inferior quality were put out onto a market which, in Britain at any rate, for six years of War had been starved of consumer goods. The result was for a time near-disastrous, but it is a tribute to the faith that manufacturers had in the intrinsic merit of their products, that in this country particularly, they persevered in the face of considerable sales resistance, both from industrial and domestic users. From being the near-miracle materials of War-time, plastics rapidly fell into disfavour, to such an extent that one encountered sales notices, such as that in a Norfolk shop window, "this article is



genuine wood, *not* plastic". It was not easy to convince the user whose raincoat had torn in first use, or whose tea cup split after a few washings, that the material was really quite good, but that some fault in fabrication had unfortunately impaired its functionality: it was not easy, but it was in fact accomplished. In Britain the problem was much more serious than in America, for example, where a material or end-product is given a ready trial simply because it is new. After a decade of intensive effort it is fair to say that plastics stand in high regard the world over and, what is more, they are now regarded as materials which can enhance the functionality of conventional materials of construction, and indeed can function alone for purposes for which conventional materials would be totally unsuitable. This near-miracle has been accomplished not only by producing plastics materials of improved quality, but also by improving their methods of fabrication: it has been proved, in fact, that it is essential to design in and for plastics. Just how this has been accomplished I hope to show later, and I hope I can also show that in this particular plastics differ to some extent from the conventional materials, which are in the main and basically natural products. Before I do this, I think it would be desirable to give a brief documentation of the current methods applied in the fabrication of plastics products. As I have already indicated, I shall treat this quite broadly and shall deal not only with the methods for the manipulation of solid plastics in powder, sheet or rod form, but also of solutions, emulsions, melts and syrups. To guide your further reading I also propose to give selected references to available literature.

## 2. CURRENT METHODS OF FABRICATION OF PLASTICS PRODUCTS

### 2.1. Moulding methods

It is fairly safe to say that the most logical way of forming a granular material into a solid end-product is by the process conventionally known as moulding. This indeed was a process in which most of us attained some degree of perfection when, with bucket and spade, we formed sand castles on the sea shore: the only difference was that we applied limited pressure and we depended on the cohesive action of water to hold the sand particles together. It is not surprising, therefore, that as finely divided solid materials were made available commercially, attempts were made to agglomerate or mould them into solid bodies by the application of pressure with or without heat, according to the nature of the material in question. Great proficiency was early attained in this art, as is evidenced by the remarkable mouldings of decorative inkstands and trinkets in gutta percha (the thermoplastic material which predated even celluloid) which are more than 100 years old, and which are to be found in the museum of the Telegraph Construction and Maintenance Company at Greenwich.

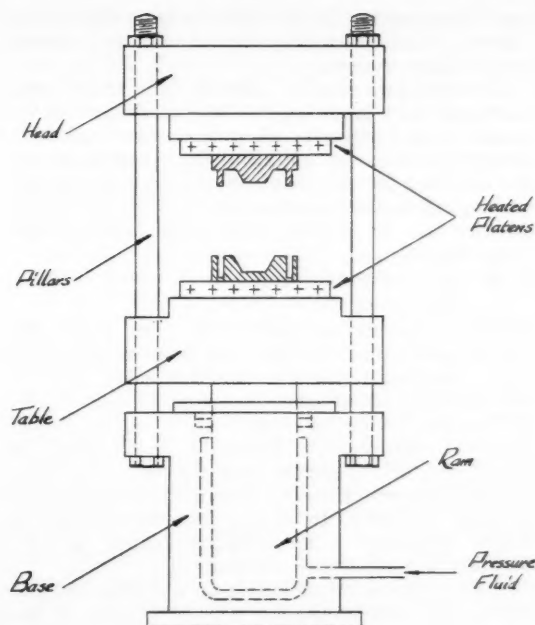
Yet, strangely enough, it was not the desire to form mouldings which mainly fired the enthusiasm

of the pioneers, but rather the desire to produce a "synthetic shellac", which could be used to impregnate paper to form insulating materials for the electrical industry and thus do more efficiently what shellac had already done. Once the pioneers had produced such synthetic resins, such as those of Baekelands p.f. type, the possibilities of moulding attracted attention, and much of the popularity of the new industry in the 20's stemmed from the success in producing moulded end-products. With the passage of years, the centre of gravity of the industry has moved further and further away from the moulding shop, until today moulding is but a part (albeit still by no means a small part) of the vast industries associated with the fabrication of plastics. Early adventures in moulding also owe much of their success to the thermosetting nature of the compositions used, and more particularly to the fact that the actual operation of forming the solid unit also converted the material from the soluble, fusible state, into the non-fusible, insoluble or thermoset state. Thus it was that the few years which followed the advent of the thermosetting compositions saw more progress in the moulding art than had been made in the decades in which thermoplastic materials, such as those based on cellulose esters, had been known. Once the potentialities of moulding had been explored, progress was rapid, and it required but a relatively few years to make possible the commercial moulding of thermoplastic and thermosetting materials alike, and indeed of those difficult materials, such as p.t.f.e., which had to be moulded into shape by cold compression and subsequently 'sintered' into the final uniform solid form by the application of heat.

Pioneer moulding methods followed the obvious pattern, the bucket and spade method, in fact, in which the powdered composition was passed into the mould and the shaped article was formed and finished (cured) therein by the application of heat and pressure. This became known as compression moulding, and it was applied most economically to thermosetting products which could be ejected solid and hot from the mould. Once a practical moulding technique had thus been established, it was not a great step to extend this to handle thermoplastics, and in the late 20's a process was developed by Eichengruen in Germany which involved the fluxing or fluidising of the composition external to the mould, and subsequently injecting this while hot into the cooled mould cavity. The moulded article solidified on cooling and was readily ejected cold and rigid from the mould into the process we know today as injection moulding. Lecturing on this subject 25 years ago, I stated quite categorically that compression moulding was the process for the production of large mouldings (and in those days we attempted bedstead ends and coffins), whilst injection moulding was particularly suitable for the moulding of thermoplastics and the production of tooth paste tube tops, small knobs and such-like diminutive units. That, of course, was before the days of polythene, when the injection of baths and bins weighing several pounds such as we know today was beyond the dreams of



Fig. 1 (right). Simple upstroking compression moulding press.



SIMPLE UPSTROKING  
COMPRESSION Moulding PRESS

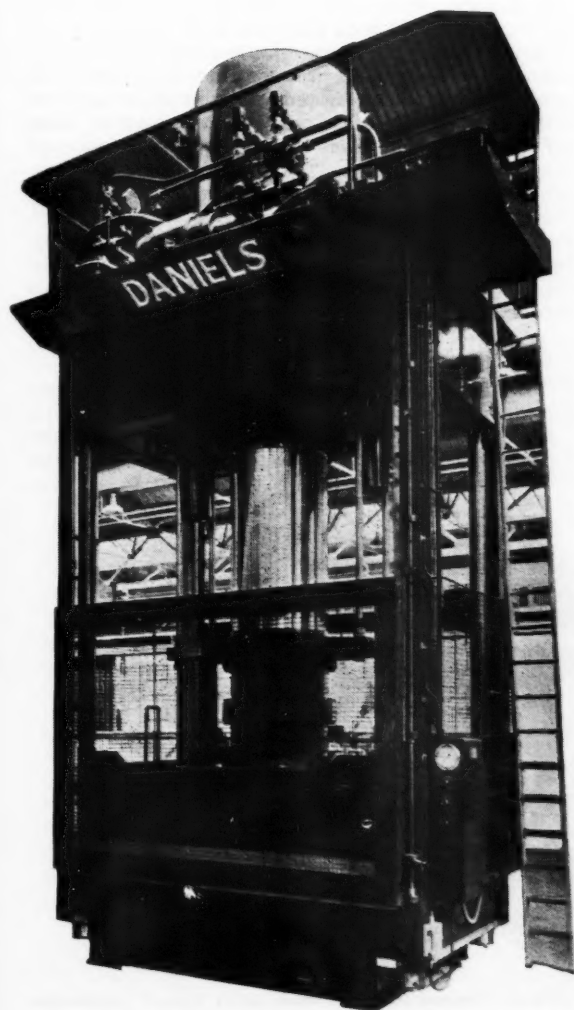


Fig. 2. Compression moulding press (250 tons) specially adapted for the moulding of reinforced plastics materials.  
(Courtesy of T. H. & J. Daniels Ltd.)

possibility. It is fair to say that the advent of the 'poly' twins, polythene and polystyrene, gave a new zest to injection moulding, and accounts for the fact that today even in large mouldings (or one may almost say particularly in large mouldings) injection is stealing the market and more and more compression shops are standing idle in consequence.

#### 2.1.1. *Compression moulding*

Compression moulding is the conventional and most widely-used method of forming thermosetting moulding materials. While thermoplastic materials *can* be moulded by this method, it is not commonly employed except for articles which are too large to be produced on the injection-moulding machines available. The importance of compression moulding as an industrial operation has grown with the thermosetting plastics industry, which may be considered to have started with Baekeland's work on phenolic moulding powders.

The main equipment required for compression moulding comprises a press, fitted with heated platens, and a mould. The press can range from the hand-operated laboratory model, of 10 to 100 tons capacity, to the hydraulically-operated industrial production unit, which is usually of the order of 250 to 500 tons capacity, but may be as high as 3,000 tons. The hydraulic press may be self-contained, that is, with its pressure-developing unit built into its structure; alternatively, when several presses are in

use, they may be coupled to a common pressure line fed by a large central pumping unit and pressure accumulator system.

Compression moulds should be made from hardened high-grade steels. The moulding surfaces should have a highly polished finish, since this determines the gloss and surface appearance which can be obtained in the moulded article. Chromium-plating can be used to advantage in some applications. Moulds can be divided into three main groups:

- (a) hand moulds ;
- (b) semi-automatic ; and
- (c) fully automatic.

Hand moulds are not fixed to the press platens, but are removed manually from the press at the end of each moulding cycle; the mould is taken apart to release the moulded article, reassembled and reloaded for the next moulding cycle. Semi-automatic moulds are firmly bolted to the platens of the press, and the moulded article is ejected from the mould by operation of the press. Loading of semi-automatic moulds is done by hand. In fully-automatic systems, the whole moulding cycle, including loading and unloading, is carried out automatically.

Most compression moulding on a production scale utilises the semi-automatic type of equipment and the mould often contains several cavities, enabling several articles to be produced in a single moulding cycle. The limiting factor governing the size and number of articles produced per moulding cycle are the capacity of the press, that is, the maximum pressure it can develop, and the area of the platens.

In carrying out the compression moulding operation, the thermosetting moulding material is loaded into the hot mould and the press is then closed and pressure applied, which forces the material into the shape of the mould cavity. At the same time, the heat of the mould causes the chemical reactions

which lead to hardening to take place. After a pre-determined time, which is dependent upon the thickness of the moulded article, the pressure is released and the article ejected. Pressing times range from 30 seconds for small articles to several minutes for large, heavy articles. With some types of material, especially the urea-formaldehyde type, it is advantageous to release the pressure momentarily at an early stage of the pressing operation, and then re-apply the full moulding pressure. This technique, known as "breathing the mould", assists the removal of volatile products which might cause porosity.

The moulding material itself is usually supplied in a coarsely granulated form, and it is often the practice to convert it into pelleted form before moulding. With large articles it is customary to make a preform which is of similar shape to the article being moulded. Both pelleting and preforming are carried out by pressing the material, while cold, under a very high pressure and they assist the moulding operation by removing entrapped air from the granulated material and generally give an easier flow in the mould. Very often the moulding material, in granulated, pelleted or preformed state, is preheated before loading into the mould. Preheating may be done either in simple convection ovens, or, preferably, in a radio-frequency field. The purpose of preheating is to improve the flow of the material in the mould and to obtain a more even and more complete cure (see Figs. 1-3).

#### *Cold moulding*

Cold moulding is a particular application of compression moulding in which the plastics composition is formed by compression in a cold mould under pressures ranging from  $\frac{1}{2}$  to 5 tons per sq. in., after which the shaped article is transferred to an oven

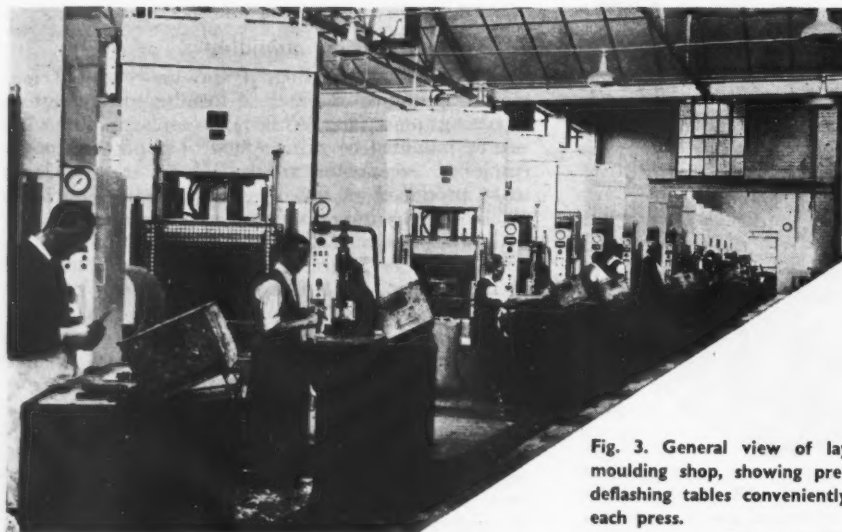


Fig. 3. General view of layout of a typical compression moulding shop, showing presses in line with changing and deflashing tables conveniently arranged for the operator at each press.

(Courtesy of British Industrial Plastics Ltd.)

and baked to harden it. Probably the most important application of cold moulding is in the abrasive industry, where abrasive grains are bonded together either by phenolic resins or by ceramic binders. A certain amount of cold moulding is also used to produce articles for the electrical industry, in which applications the binders used are usually bituminous in nature. A further application is the production of foundry cores and moulds in which sand is bonded with drying oils (or more recently, urea resins).

The particular advantages of cold moulding are:

1. A high rate of production is possible, since the time in the press is very short, only just sufficient to form the article.
2. Articles of very thick section can be produced with little more difficulty than small articles. This is of particular importance in the manufacture of grinding wheels, which are often produced in thicknesses of more than 6 in. To cure an article of such thickness in a hot press would be quite uneconomic because of the long moulding time which would be required.

The disadvantages of cold moulding may be summarised as:

1. The surface finish is invariably inferior in appearance when compared with hot moulded articles. This is of no importance in the abrasive and foundry applications and only of very slight importance in electrical mouldings, since these are, in the main, intended for utilitarian and not decorative purposes.
2. Very often a machining operation is needed to finish the moulded articles to the exact dimensions required. This adds to the cost of the articles.
3. Difficulties with warping are sometimes encountered with thin-walled sections. This can often be prevented by small changes in design.

### 2.1.2. Transfer moulding

For intricate articles, perhaps having undercuts, small moulded holes or delicate inserts, the normal compression moulding operation is unsuitable. In such cases, the technique known as transfer moulding or plunger moulding can often be used. The characteristic feature of transfer moulding is that the thermosetting moulding material is softened by heating in a chamber separate from the actual mould cavity, but connected to it by one or more channels. When hot and in the plastic state, the material is forced by means of a plunger through the channels into the mould cavity where hardening is completed. The process thus has some points of resemblance to the injection moulding process for forming thermoplastic materials.

In the United Kingdom down-stroking presses are most widely used for transfer moulding, but up-stroking presses can be used and are more common in America. The process of transfer moulding, which was invented in 1926 by the Shaw Insulator Co. of New Jersey, was greatly helped by the introduction of preheating techniques, especially that of radio-frequency preheating. By this means, the speed of

transfer from the "transfer pot" to the mould cavity can be considerably increased, and lower pressures are needed. Further, the degree and uniformity of cure can be improved. The earlier products of transfer moulding tended to be less rigid on ejection from the mould than products formed by conventional compression moulding, but the development of materials specially formulated for transfer moulding has led to a great improvement in this respect.

As compared with compression moulding, transfer moulding usually allows a shorter moulding cycle and permits closer tolerances to be maintained. Other advantages are that mould costs can often be reduced and finishing costs are almost invariably lower. A disadvantage is that a certain amount of material is lost in each moulding cycle because of the residues left in the transfer chamber and filling the channels between the chamber and mould cavity. Being fully hardened, this material cannot be reworked in the way that thermoplastic scrap can be recovered. A further disadvantage is that materials containing fibrous fillers, designed to have an improved impact strength, often suffer some loss in strength when transfer moulded. For general purpose materials which use wood-flour as a filler, no significant loss of mechanical strength is noted.

### 2.1.3. Injection moulding

Injection moulding is the fastest and the most widely used of the plastics fabrication processes, and nearly all the thermoplastic materials can be injection moulded. Although so simple in principle, the process is in fact most complex and to produce top quality articles careful mould design, sound knowledge of machine operation and maintenance and experience with the actual process are essential requirements. The process is dependent upon the peculiar properties of thermoplastics materials which can be softened by heat to a high viscosity condition in which they can be forced to flow under pressure to take up whatever shape is required.

The injection moulding process consists of several distinct steps which are very briefly as follows:

1. A measured amount of thermoplastics material is metered into the injection cylinder.
2. A plunger forces this material forward through the injection cylinder, where it is heated to the required temperature and is transformed to the (high viscosity) molten state.
3. Molten material is forced forward by the plunger into a closed mould cavity, which it fills completely.
4. The thermoplastics material is here cooled so that it returns rapidly to the solid state, at which point the mould is opened and the solid moulded unit is ejected.

To obtain efficient and economical operation of the process there must be a compromise between conflicting requirements. For economy of operation the heating/cooling must be as short as possible, but the material will only flow satisfactorily within a relatively narrow temperature range, most materials being degraded chemically should the temperature



rise too high. The heated material is injected into a relatively cold mould which chills the surface of the charge as it advances into the mould cavity, restricting or stopping completely the flow of the surface material. This immediately places restrictions upon the thickness range that can be moulded, so that special techniques are required to produce thin sections (below 25 thou.) and thick sections (above  $\frac{1}{8}$  in.). As the density of plastics materials changes under the influence of heat and of pressure, a sequence of volume changes occurs in the injection moulding process. Polystyrene, for example, is compressible to the extent of 6.8% at 450°F and 16,000 p.s.i. pressure, whilst one cubic inch of polystyrene at room temperature will expand to 1.09 cubic inches on heating it to 450°F.<sup>1</sup>

To stress the complexity of the process, and to stress one aspect of the close attention the fabrication of plastics must have as compared with conventional metals, it is helpful to consider in detail the volume changes which take place. Envisage an empty mould of 1 cubic inch in volume, and a cylinder at room temperature containing 1 cubic inch of polystyrene. If the polystyrene is heated to 450°F without the application of pressure, the volume increases to 1.09 cubic inches. The application of 12,000 p.s.i. pressure applied to move the polystyrene from the injection cylinder into the mould, reduces the volume to 1.034 cubic inches, of which, of course, only 1.0 cubic inch will enter the mould cavity, leaving 0.034 cubic inches remaining in the injection cylinder. The material in the gate (the part between cylinder and mould) freezes so that the polystyrene cannot move into or out of the mould cavity. Then the polystyrene in the mould is cooled to room temperature. The 1 cubic inch of polystyrene shrinks at room temperature and zero pressure to occupy a volume of only 0.97 cubic inches. The difference between the volume of the moulded piece and that of the mould cavity at room temperature is the 'mould shrinkage'. If the moulding has cooled in a perfectly uniform manner the cube would be a perfect image of the cavity, only smaller in each linear dimension by about 0.010 in. Uniform cooling is not easy to obtain and, therefore, each linear dimension may differ. The injection pressure may be increased to force a greater weight of material into the cavity so that there is less mould shrinkage, but it then becomes more difficult to open the mould.

The process is further complicated by the varying physical state of the material between the feed and delivery ends of the cylinder. A considerable pressure drop occurs as the cold plastics material is pushed through the heating cylinder and becomes warmer until it is plasticised sufficiently for fluid flow, largely because of the friction of the cold granules against the sides of the heating cylinder. It is important to conserve the pressure within the heating cylinder so that the material may be transferred to the mould at high velocity when the plunger is brought forward. Much thought has been given to the design of the nozzles and sprues to allow rapid filling of the mould cavity without pressure loss, while the introduction of pre-plasticising units, which ensure that the

moulding material is heated sufficiently to bring it to molten condition before it is fed into the injection cylinder, has helped considerably in this regard.

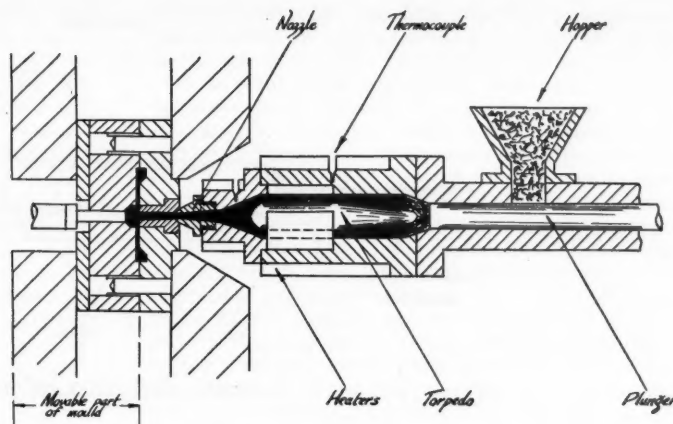
The operation of filling the mould should be followed as soon as possible by freezing at the gate to prevent the material from flowing backwards once the injection plunger has been withdrawn. Whilst the premature removal of the injection plunger pressure will cause the moulding to have sink marks or vacuum bubbles, a sign of excessive or uneven mould shrinkage, too long a plunger dwell time may lead to sticking, warping, crazing and cracking. Once the mould cavity is initially filled with polystyrene, about 7% more may still be packed in. Prolonged packing of the moulding material into the mould can result in high residual pressure in the cavity after the moulding has solidified. The residual pressure multiplied by the co-efficient of friction between plastic and mould (the co-efficient of friction between clean steel walls and polystyrene is about 0.1), times the area of side walls of the moulding, is the total force required to slide the moulding past the walls as the mould is opened. Too much residual pressure can cause a mould to stick shut, simply because the mould opening device has not the force required to overcome the friction between the moulding and the walls. A mould may stick shut momentarily and then suddenly open without any apparent reason after the pressure has decayed sufficiently to reduce the residual pressure.

The use of a restricted (or 'pin-point') gate allows the plastics material in it to cool and solidify quickly, so that the plunger may be withdrawn early in the cycle before packing has occurred. Various mechanical devices have been developed to seal the mould as soon as the filling stage has been completed. For certain applications a mechanical cut-off device functions better than a restricted gate, because sealing occurs immediately upon withdrawal of the plunger. Mechanical cut-offs have been used with success on thick section mouldings to produce mouldings having higher heat distortion temperatures, indicating less residual strain in the moulding.

It is necessary to control the flow of the material in the mould cavity in order to produce high quality injection mouldings. Except with some restricted gates, the gate should be located at the thick section of the mould but when restricted gates open into thick section cavities, jetting often occurs because the velocity of the plastic is too high. Under these conditions the moulding material cannot form a chilled, even-flowing front and unsightly weld lines, which are also points of weakness, may be seen in the product. The thickness of the wall section is of considerable importance in controlling the flow in a mould cavity. In large flat area pieces, the plastic naturally prefers to flow to any sections having slightly greater thickness. The mould wall should be uniformly thick within 0.004 in. or less in a given cavity, and of the same thickness from one cavity to another in a multiple cavity mould. One thin-walled cavity in a mould can demand so much pressure for filling, that the moulding may stick in a neighbouring perfect cavity. Mould temperature is also a



Fig. 4. Injection moulding — diagrammatic representation of the general layout of the injection moulding machine, tracing the course of the granular polymer from the hopper through the heating zone and thence into the closed mould.



### INJECTION MouldING

factor of significance. Hotter mould surfaces help the flow in a thin section much more than they help it in a thick rim. Good mould temperature control comes from having a large amount of heat exchange fluid, at the temperature within  $5^{\circ}\text{F}$  -  $10^{\circ}\text{F}$  of the desired mould temperature, circulating through channels in the mould itself.

On multiple cavity moulds it is extremely important to balance the size of the gates, so that all cavities fill uniformly and simultaneously. It is particularly important when restricted or pin-point gating is employed in a mould construction, because if the flow through a restricted gate ceases momentarily the gate may freeze, making it impossible to start the material flowing again.<sup>2</sup>

The many factors which affect the control injection moulding operations that have been discussed are, fortunately, ones over which control is possible. Many of these individual functions are relatively simple, but their inter-relation with others adds considerable complexity. There is one complicating factor over which complete control is not yet possible; that factor is the fluidity of the plastics materials. During the moulding cycle, the material exists in both a solid state and in a comparatively fluid state, with varying intermediate degrees of fluidity. Funda-

mental studies have led to a measure of control over the process which now makes it feasible to produce expendable containers with wall thicknesses of 15 to 25/1,000ths of an inch. But as the trend to thinner sectioned mouldings and to more rapid automatic cycles has continued, the demand has been to control more closely the pressure drop in the cylinder. To this end, weigh feeding has been introduced and developed so as to maintain constant the plug of unheated granules immediately ahead of the plunger.

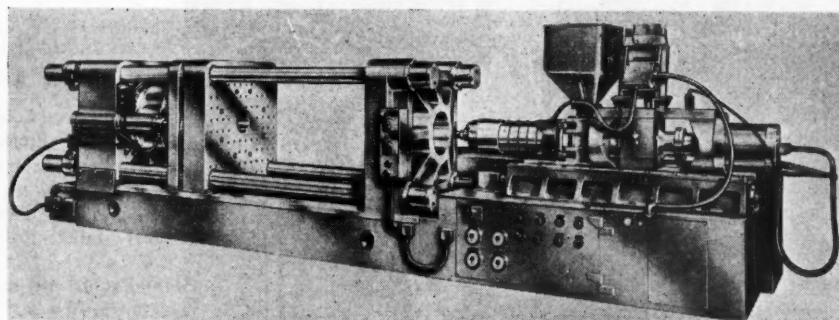
A further step in the same direction has been the development of pressure control from either nozzle or die, from which method a degree of control even beyond that of weigh feeding, has been claimed. A pressure measuring head fitted to either the die or nozzle controls a relief valve in the hydraulic pumping system and can make allowances for changes in the material viscosity<sup>3</sup> (see Figs. 4 and 5).

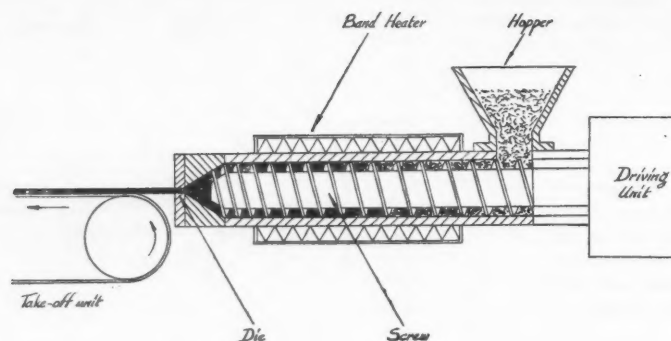
#### 2.1.4. Extrusion moulding

The extrusion operation consists of forcing the molten material through an orifice to obtain a desired shape and cross-section, and can be readily applied to all thermoplastic moulding materials. The product is of continuous long length and of uniform cross-section, and is thus differentiated from moulded

Fig. 5.  
A typical modern injection  
moulding machine.

(Courtesy of  
R. H. Windsor Ltd.)





SIMPLE EXTRUSION MACHINE

Fig. 6. Diagrammatic representation of a single screw extrusion machine showing the passage of the granulated thermoplastic composition from the hopper through the heating zone and die, and thence on to the take-off table.

products, which are usually complex, discontinuous shapes. Extrusion has steadily gained popularity in recent years and today extruded products range from doll's hair to chemically resistant pipe, from film for packaging to wire coverings.

The plastics extruder operates on a simple principle which is illustrated diagrammatically in Fig. 6. A screw rotates in a closely fitted cylinder, jacketed for supplying the necessary heat. Plastics material is fed in one end of the screw and forced by its action through the heating zone and finally through a die. The key to successful extrusion is sufficient intermixing of the molten materials to ensure uniform heating to the proper temperature as it leaves the extruder orifice. The extruder should be of sufficient length to accommodate at least three independent heating zones. The hopper zone should be kept below the softening point of the material, while in the following zones the temperature is

gradually increased and the material compressed. In many extrusion machines, screens or breaker plates are placed in the path of the plastics between the screw and the die with a threefold purpose. Firstly, they prevent foreign material from reaching and damaging the die; secondly, they help to change any helical flow to straight line flow before the material enters the die; and finally, they increase the back pressure. A modern extrusion machine is illustrated in Fig. 7.

As compared with dies used for injection or compression moulding, those for extrusion dies are relatively simple and inexpensive. Some die assemblies extrude straight through along the axis of the screw, while others are of the cross-head type which extrude at right-angles to the screw axis. Extrusion dies to produce complicated shapes cannot be designed on the basis of theoretical considerations, but are worked out as the result of experience and trial and error.

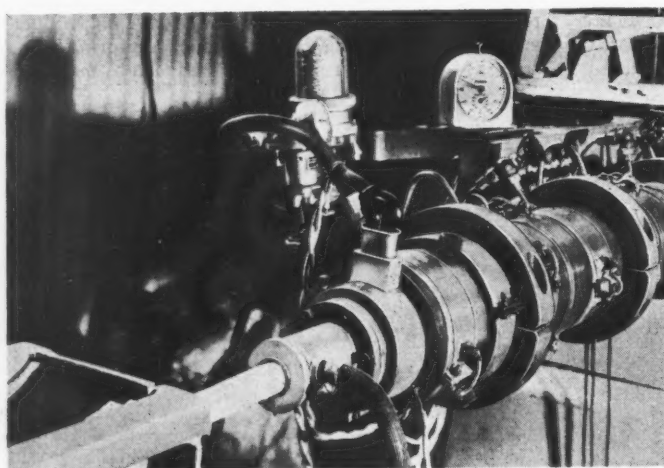


Fig. 7. A modern extrusion machine.

(Courtesy of  
Projectile and Engineering Co. Ltd.)

In general, to ensure good flow characteristics, die surfaces should be well finished. The die opening is usually larger than the desired extruded product, so that a small amount of pull-down can bring the section to the finished size. This gives improved size control and higher production rates.

Various conveying systems are in use to hold the extruded plastic section in shape while it cools. Cooling may be accomplished just by convection in air, by forced air jets, or by running through water troughs. Proper design of such take-off and cut-off equipment can greatly extend the useful range of sizes which may be made with extrusion equipment.

Since polystyrene granules with an apparent density of 0.55 must be compressed 1.9 times to reach the finished density of 1.05, a screw with a compression ratio of at least 2 is required to give good results. This compression may be obtained either by decreasing the screw pitch or by increasing the root diameter, or by a combination of both. The decreasing pitch screw has less tendency to pulsate and the pressure transmission is somewhat better, while an increasing root diameter screw allows better heating through thin plastic sections, although the material has a shorter path to travel than in a variable pitch type. The increasing root diameter type is recommended for the extrusion of polythene.<sup>4</sup> It is important to shape the flights so that the material is forwarded axially rather than forced radially away from this group towards the cylinder wall. The material should be heated to a progressively increasing temperature as it moves along the screw, otherwise it may become stationary in the flights, refusing to move forward.

The flow of material in an extruder is made up of three processes:

1. *Drag flow* caused by the rotation of the screw within the cylinder;
2. *Back flow* through the screw channel as a pressure build-up occurs at the die head; and
3. *Leak flow* across the flight of the screw.

The last is a small item when screw and cylinder are close fitting and is usually neglected in simplified discussions. For the melt zone the basic equation

becomes:  $Q = \alpha N - \left(\frac{\beta}{\eta}\right) P$  in which  $Q$  is the output;

$\alpha$  and  $\beta$  are respectively forward and back flow constants, which depend only on the screw dimensions;  $N$  is the screw speed and  $P$  is the pressure developed at the die;  $\eta$  is the viscosity of the material. The equation predicts, for example, that the back flow will be reduced and output increased by using a material with higher viscosity while consideration of the nature of the constant  $\alpha$  and  $\beta$  leads to the conclusion that the screw design should be tailored to the die requirements. The approximate theory of the flow of material through dies, which can be applied only to certain geometrical shapes, enables the necessary flow rates to be determined as a function of pressure build-up and the screw characteristics.<sup>5</sup>

The hit-and-miss methods so prevalent in the past in extrusion work are being less widely used as an

increased understanding of the process is disseminated and extended. Examples are the attention being given to the use of a valve between the screw and die head to control back pressure, and the use of a rotating valve to interrupt the extruder output in such a way as to provide a method of moulding small articles.<sup>6</sup> These serve to illustrate the advances that will accrue in the near future from the experimental and theoretical work of the last few years. To date, theoretical attention has been given to metering type screws in which the last three or four flights have constant depth, because in such cases not only is the theoretical approach simpler but also practical improvements, such as increased uniformity of output, occur from using such a screw. (Introduced initially for use with nylon, where they have been shown to be advantageous, metering type screws are now in use for most extrusion materials.) The rear end of the extruder screw which compresses unmelted granules, or the central melting zone, have not proved so amenable to theoretical treatment, but progress has been made in understanding the plug flow which occurs at the feed end.

The mechanical work done on the plastics material by the screw can generate considerable frictional heat which the heating medium must be able to absorb and carry away. Oil and steam work well in this regard, but not an electrical heating system. Consequently, it is necessary that a cooling and temperature control medium be used in conjunction with an electrically heated cylinder. In modern designs the cylinder is channelled for passage of air, low pressure steam, water or oil. In recent years there has been some development of adiabatic (or 'autogenous') extrusion, in which only work heat is used once the extrusion machine has been brought into equilibrium. The process has aroused considerable interest as well as severe critical comments, on the grounds that for any particular die only one screw speed will generate the necessary material temperature via work heat and so the extruder conditions would be too narrow. It is claimed, however, that a natural controlled balance of temperature is achieved in contrast to the hunting that occurs with the conventional heater-thermocouple controller arrangement. It is suggested that autogenous working can eliminate the need for most of the special temperature control equipment.<sup>7</sup>

A large proportion of extrusion equipment is devoted to the production of thin sheet either for packaging or vacuum forming. Blown polythene film is produced by extruding a thick tubular section vertically upwards and introducing air into the tube to expand it to the desired diameter and wall thickness. Air is maintained in the tube by the closed die at one end and motor driven squeeze rolls at the other. It is of the utmost importance that the wall thickness of the tube be uniform to ensure wrinkle-free film and even winding on to the reel. The internal air pressure, extruder output, die adjustment, take-off speed and material temperature, are factors which control the gauge of the film. When the extrusion of blown polythene film is started the tube, as it issues from the die, is drawn manually to the pinch rolls which take it off at a uniform rate. Air



is then admitted slowly through the centre of the mandrel to expand the tube to the desired diameter. The air supply is then shut off, leaving a locked volume of air within the tube. For vacuum-forming toughened polystyrene sheet is made by extrusion in ever-increasing quantities, in a thickness range of about 20-180 thousandths. The output from a large slit die, up to about 4 ft. wide, is fed to a set of cooling rolls where, if required, a thin polystyrene foil is laminated on to it to give a high gloss finish. After passing through haul-off rolls the material can be cut into predetermined sheet sizes by the operation of a guillotine by photoelectric cell control, or wound up into rolls.<sup>8</sup>

As higher production outputs are demanded, another extrusion phenomenon, in addition to work heat build-up, has been encountered, namely, the development of surface roughness on the extrudate. Previously the appearance of surface roughness, when the shear stress reached a critical value, had been explained in terms of orientation. More recently, however, this has been shown to be caused by a break-up of the flow in the die approach at shear stresses above a critical value. An increase in the material temperature, or the use of a resin of lower viscosity, increases the output of smooth extrudate.

## 2.2. The production of sheet plastics

Just as it had been logical to mould comminuted plastics powders into solid units, so there was ample precedent for converting these materials into sheet form, the idea being, of course, that these might be used much as had metals and woods from time immemorial. This having been conceived, the method of operation rapidly matured in what soon became known as the 'celluloid' technique, since it was developed primarily for the working of celluloid, in which the plastic was made into a solid block from which sheets were sliced with an inclined knife. Likewise, for many years, it had been known to bond paper together into relatively thick sheets by means of natural resinous adhesives, and the advent of bonding agents which could be rendered infusible, naturally gave a new impetus to this industry, and laid the foundations for what has for many years been virtually a separate industry within the field of plastics, the production of laminates. Today it is fairly safe to say that laminates have done more to popularise plastics with industrial and domestic users than any other single material, or indeed groups of materials in this versatile industry, and 'Formica' and 'Warerite', to mention but two, are almost household names the world over.

What had been successful with paper was naturally explored with thin sheets of wood, and plywood resulted. Whilst this industry was founded on the use of water-soluble natural adhesives, it leaped into significance when plastics bonding agents were used. Likewise, what had been successful with regular sheets of wood was extended to the conservation of irregular wood particles, sawdust and shavings, so much so that today, what started as an expedient to conserve wood waste is growing into a streamlined industry producing a specification material which can

successfully compete with board wood in many markets.

### 2.2.1. The 'celluloid' technique

As its name implies, this method ranks among the pioneers used in sheet production. Alcohol-wet nitrocellulose (10.8% N) is intimately incorporated with camphor in a Z-blade mixer, and this dough-like mixture is then pressed in hydraulic presses into blocks of standard size 54 in. × 24 in. × 6 in. firmly anchored to a heavy iron bed plate. Sheets of varying thickness are sliced from the block by means of an inclined knife, which is automatically traversed downwards after each cut. The sheets so produced are "stoved" for periods up to six months according to the thickness, to remove volatile solvent, and are finally "polished", to remove the cutting or "knife" lines, by hot pressing in a multi-platen press between highly polished nickel plates; alternatively embossed surfaces can be produced by hot pressing between plates suitably engraved. Patterned sheets, such as the well-known tortoiseshell material, are produced by incorporating materials of varied colour in the block, and slicing and repacking into a block several times, if necessary, until the desired configuration is attained. As may be imagined, this is a craftsman's job and one in which a considerable amount of traditional skill has been built up by the firms in this industry. In spite of the advances made in extrusion methods, the slicing method still claims its production quota, especially for celluloid, in which the difficulties and dangers of extrusion are many. Continuous sheet was at one time produced in Germany by this method, the sheet being "peeled" from a cylindrical block by a constantly advancing knife, very much on the lines of wood veneer production; the method appears to have been unable to survive competition with the more accurately controlled cast film and extruded sheet.

### 2.2.2. The production of high pressure laminates

The process of making high pressure laminated products consists of impregnating sheets of material with a thermosetting resin, drying to remove solvents and to adjust the stage of cure of the resin, and finally stacking the dried, impregnated sheets and consolidating them into a hard cured product by the application of heat and pressure (Fig. 8). The sheet materials used are most commonly paper or woven fabrics based upon various fibres, while the most important resins used are the phenolics (usually based on cresol) and the melamines.

The resins are dissolved in suitable solvents, usually alcohol or a mixture of alcohol and water, the solids content and viscosity of the solutions being carefully controlled. In the impregnation stage the sheet reinforcement is unwound from a roll and passed through a bath of the resin, and then through pressure rollers which control the amount of resin taken up and ensure complete impregnation. In some cases, such as for the production of wrapped laminated tubes, it is desired to coat the reinforcement on only one side, rather than thoroughly impregnate it. This is achieved by using a pick-up



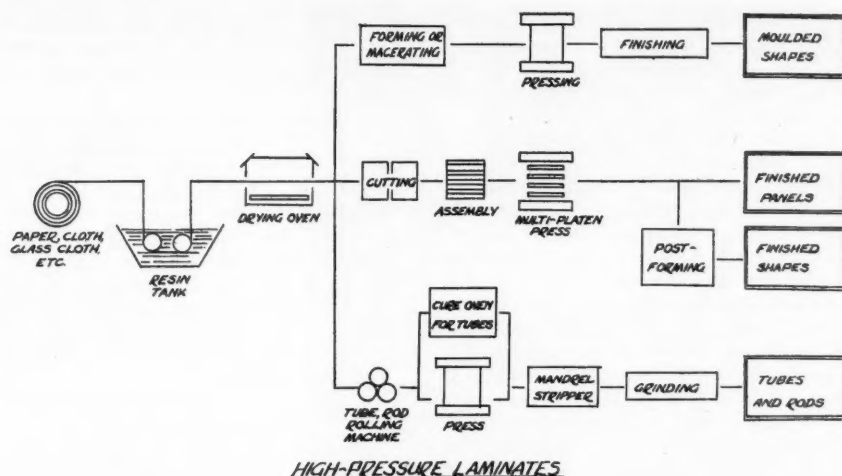


Fig. 8. High pressure laminates — diagrammatic process sheet showing the production of high pressure laminates from the basic raw materials (paper, fabric, glass cloth and bonding resin) up to the finished sheets, rods, tubes and moulded shapes.

roll which is in contact with the resin in the bath and resin is transferred from this roll to the reinforcement sheet, often through a system of intermediate rolls. Other methods of coating employ doctor blades which apply a controlled weight of resin solution to the paper or fabric.

After coating or impregnating, the sheet passes directly to the drying plant. This consists essentially of a large hot-air oven in the form of a tower or tunnel in which the solvents are removed by a carefully controlled heating cycle, and passed to the solvent recovery system. In this stage the degree of cure of the resin is also adjusted to the optimum point for the subsequent laminating operation. The final zone of the oven is sometimes used as a cooling unit, but an alternative method of cooling is to pass the sheet between water-cooled rollers. The sheet is finally reeled on another roll. Tunnel dryers are up to 10 ft. wide and may be as much as 200 ft. long. The rate of production of impregnated sheet varies with the material but is usually within the range 15 ft. to 20 ft. per minute.

The next stage, that of laminating the impregnated sheets into the final product, employs multi-daylight presses with heated platens, which may have an area of 100 in.  $\times$  50 in. in the largest presses. Platen temperatures of about 150°C are used for phenolic-resin based laminates, while pressures are of the order of  $\frac{1}{2}$  to 1 ton per sq. in. The cure time depends upon the thickness but a cure time of 20 minutes for a laminate  $\frac{1}{8}$  in. thick is customary. Some work has been done on the curing of laminates by the application of a radio-frequency field while under pressure, and considerable shortening of cure time is claimed for this method, especially for thick laminates.

It is essential that the platens of the press should be parallel, otherwise the finished laminate appears patchy. The impregnated sheets are placed between

metal plates which may be of stainless steel, chromium plated steel or copper, and the assembly inserted into the press. Frequently a preloader is used in which several laminates are stacked prior to simultaneous insertion into the press. The plates must be spotlessly clean, and either highly polished or finished to a matt surface as required in the final laminate. A film of a lubricating substance, such as zinc stearate, is usually spread over the plates to prevent adhesion of the resin. In order to avoid warping troubles, the press is usually cooled before releasing the pressure.

Laminates based upon phenolic resins are deep brown in colour and have little decorative value. By making the top plies of the laminate in urea- or melamine-resin impregnated sheet, products with light-coloured surfaces, carrying printed designs, if so desired, can be obtained. Alternatively the whole laminate may be made from the amino-resin impregnated material, in which case translucent effects and inlaid designs can be achieved. By incorporating suitable chemicals fluorescent laminates can be made, while heat resistance can be considerably improved by placing a layer of metal foil immediately below the decorative surface.

Laminated tubes can be machined from sheet material, but it is more usual to make them by winding the treated paper on a mandrel. Heat and pressure are applied by means of rollers during the winding operation, and curing is completed by heating the tube on its mandrel in an oven. After cooling, the mandrel is extracted and the tube machined to the correct external dimensions on a centreless grinder.

An alternative procedure is to mould the tubes, after winding, by heating under pressure in a split mould. The heat and pressure may be applied by a press, or a moulding box equipped with clamps

may be used and the whole assembly placed in an oven. Rod can be made in the same way by winding on a mandrel of small diameter, which is removed before moulding. During the moulding operation the tube collapses to form a rod.

Special grades of laminated sheets can be "post-formed". In this operation the sheet is heated, and while hot is shaped over a die by applied pressure. Pressure is maintained until the article has cooled sufficiently for it to retain its shape after removal from the die. Infra-red ovens or high-frequency generators are the best means of heating the sheets before post-forming, although other methods such as convection ovens, oil baths and fusible alloy baths have been used. Post-forming moulds are constructed of cheap materials such as wood, cast resin, etc. Very little pressure is required to form the heated sheet, so that light rapid-acting toggle or cam presses can well be used. The secret of successful post-forming is that the whole operation must be carried out quickly.

### 2.2.3. The production of laminates—low pressure

The field of reinforced plastics is growing rapidly and new methods of fabrication are constantly being developed. To give an adequate survey of all the methods currently in use is impossible in the time available and, therefore, only those processes which are most widely used are described.

#### 2.2.3.1. Wet lay-up process

This process, and simple variations upon it, is most widely used for the fabrication of fairly large articles in glass-fibre reinforced plastics. In essence the process is simple, but to maintain a good quality of production it is desirable that the factory should be controlled as regards temperature and humidity.

The first requirement is to prepare a mould, which may be constructed in wood, plaster or, very often, in glass-fibre reinforced polyester resin. The working surface of the mould is made as smooth as possible and then polished with a polish containing hard waxes. A film of a material which is incompatible with polyester resin is then applied by brush or by spray to form a "parting layer". In the next stage, a "gel coat" about 0.010 in. thick is brushed on. This gel coat consists of a polyester resin, usually specially formulated to have a certain degree of resilience, and pigmented to the desired surface colour. The gel coat is allowed to harden to the stage where it is just tacky to the touch and then the first layer of glass-fibre reinforcement is applied. Further resin is applied and worked into the glass with a stiff brush and split washer rollers until the glass is thoroughly impregnated. This resin is allowed to harden to the tacky stage and further plies of glass and resin are built up in the same way until the desired thickness has been achieved. The assembly is then allowed to cure, the process sometimes being accelerated by gentle heating. In some cases, the assembly is enclosed within a flexible bag and pressure applied to the laminate by withdrawing the air from inside the bag. Somewhat higher pressures can be applied if desired, by

reversing this process and inflating a flexible bag against the laminate. If steam is employed as the inflating agent the heat also serves to accelerate the cure of the resin.

The glass fibre reinforcement is obtainable in a variety of forms, for example, woven fabrics in several kinds of weave, chopped strands of glass about 2 in. long bonded into a mat form either by adhesives or by mechanical means, and woven rovings. The multiplicity of reinforcements can be used to advantage since it is possible, by choice of reinforcement and the position in which it is placed in the laminate, to give the product increased strength in any desired direction. Designing of plastics structures in the full sense of the term is thus a possibility.

#### 2.2.3.2. Preform moulding

Preform moulding is used for the production of large runs of fairly small components. Basically the method comprises forming a "preform" of the article to be produced, from chopped glass fibres bonded with resinous adhesives. This preform is then transferred to a heated metal mould, polyester resin is distributed over it and the assembly is pressed under a light pressure, usually not exceeding 100 p.s.i., until cure is completed. Articles such as suitcases, washing machine agitators, etc., have been successfully produced by this method.

Several methods are used for producing the preforms. The first method to be developed, which is still probably the most widely used, employs a "plenum chamber" into which glass fibre rovings are fed. The glass passes through a chopping device as it enters the chamber and is thereby cut into short lengths which fall down the chamber and are collected upon a perforated screen of appropriate shape, positioned at the bottom. Vacuum is applied to the screen to assist the collection of the fibres. At the same time a resinous bonding agent is sprayed into the chamber and is collected along with the glass fibre on the screen. Many resins, both liquid (or emulsified) and solid powdered materials have been used as bonding agents, but present practice prefers a solid polyester resin for this purpose. The preform, on its screen, is withdrawn from the chamber and the bonding agent is cured by heat to the stage where the preform can be handled without disruption.

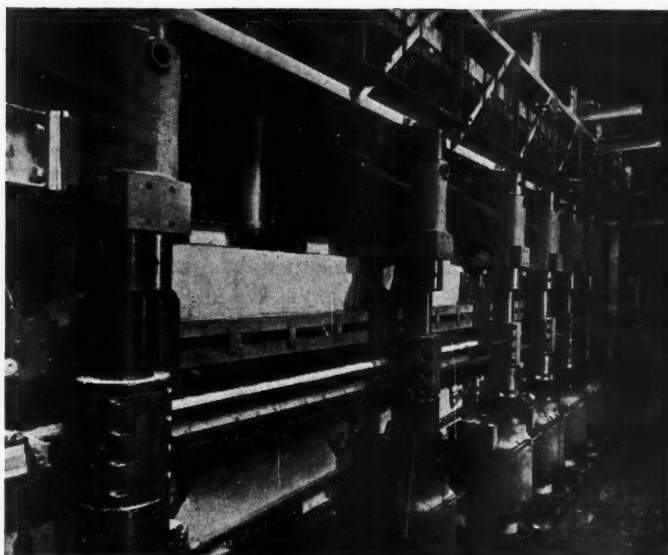
Another method of making preforms which has been more recently developed is to spray the resinous binder and chopped glass on to a screen through which suction is applied. This method has the advantage of being able to produce larger preforms, but the quality of production is very dependent upon the skill of the operator.

### 2.2.4. The production of wood laminates — plywood, densified wood and particle board

The production of laminates or multi-ply wood actually long predates the extensive use of synthetic materials as bonding agents. Once these had been firmly established, and particularly those of the

**Fig. 9. Side view of the Bartrev continuous press for the manufacture of particle board, showing the six interconnected pressure columns, No. 6 column being closest to the camera, and furthest away from the compression nip. (The board under heat and pressure from the moving platen can be seen as a white line passing midway behind the base of the pressure columns.)**

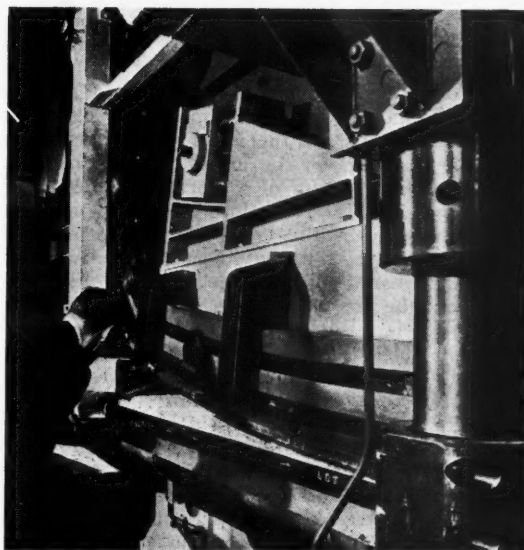
(Courtesy of International Plastics Ltd.)



thermosetting variety, then they very naturally replaced the water-soluble natural adhesives on which the plywood industry was founded. The change from natural to synthetic was not an obvious one; indeed, many users may only have become aware of the fact that any change had actually taken place when they found that their plywood no longer delaminated when immersed in water or became exposed to the weather. Much of the advance in this direction was made under the secrecy of war-time, when aircraft, such as the famous "Mosquito", were literally stuck together with glue; but the glue was a synthetic polymer. Since then, boil-resistant bonding materials have been developed which have enhanced the performance of current plywood.

Plastics also advanced the production and performance of laminates in which multi-ply wood was not only bonded together, but in which the resin actually penetrated the plys so bonded. These so-called densified woods were made before the War in France under the name 'Bois Bakalise', and later in Britain as 'Permali'. They have remarkable performance and can be worked and used for many purposes, much in the same way as metals, and they have the great advantage, of course, that they are considerably lighter.

The procedure having been established to bond together massive sheets of wood, it is not surprising that similar attempts were made at the other end of the scale, i.e. to bond into a usable sheet the finely comminuted wood which clutters as refuse sawdust the yards of every sawmill and wood working shop. At first the idea was to find an outlet other than fuel for this waste, which is to many industries a sheer embarrassment, but in the process of time the products of the new industry have gained status, and after many tribulations, are now established as specified materials variously known as sawdust board or chipboard, but now designated more usually in



**Fig. 10. Bartrev machine — the nip. A view of the Bartrev machine showing the 'carpet' of resinated wood particles entering the pressure 'nip'. (The individually heated pressure platens can be seen coming into line at the point where the operator is making his observation.)**

(Courtesy of International Plastics Ltd.)

Europe under the officially recognised title of particle board. There is, however, one significant difference between the products of this industry today and those of the pioneers of a decade ago. Then it was a case of making something usable out of a heterogeneous collection of unusable comminuted wood waste. Experience has shown that this can only



be done satisfactorily if attention is paid to the geometry of the wood particle, so that today attention is concentrated on the production of wood particles of optimum size and configuration, starting with the tree off-cuts and trimmings which would be useless for board timber. The aim is possibly the same, but it operates one stage further back as far as the wood is concerned.

There are, of course, many variants in the process as it is operated commercially today, but in essence it entails the controlled comminution of wood, admixing with this a controlled amount of a binding resin (usually u.f. or p.f.), so as to give a mass of constant and uniform resin and water content. This is then spread into thin layers or "carpets" depending on the thickness and final density of the sheets to be produced, and finally these sheets are constituted under the application of heat and pressure either discontinuously in a multi-platen press, or continuously in a caterpillar type rolling press. The static methods are possibly well known to you, so I will only draw your attention to one type of continuous press which has been developed in this country by Bartrev. The press is, in essence, two caterpillar tracks which can be heated to a controlled temperature and which carry two facing stainless steel bands. Wood chips of predetermined optimum shape and moisture content are treated with a controlled quantity (of the order of 5% - 7%) of urea formaldehyde resin syrup suitably catalysed to give rapid cure, and this is fed to a hopper, from which it is spread on the lower band of the continuous press by means of a vibrating feeder. This uniform 'carpet' is carried forward first under a radio frequency heating unit, and thence into the 'nip' of the press where it meets the overhead track, and where the loose layer is compressed into a sheet of the required density (0.4 - 0.75) and thickness ( $\frac{1}{4}$  in. - 1 in.). The pressure is maintained at 300 lb. - 500 lb. per sq. in. and temperature at 140°C-150°C as the compressed mass moves through the pressure zone, where the pressure is applied from six hydraulic columns. These can be seen from the photographs (Figs. 9 and 10) which show the 'nip' with the resin woodchip 'carpet' clearly visible as it enters, and also the compressed sheet on its way through the pressure zone, and the six pressure columns. When the cure of the resin has been substantially completed, the sheet passes out of the press, and is cut into predetermined lengths by means of a flaying saw. The 'Bartrev' process is a triumph for integrated chemical and mechanical process precision, and makes possible the continuous production of chipboard at speeds ranging from 6 ft. - 18 ft. per minute, according to the thickness.

#### 2.2.5. *Production of laminates with discontinuous inorganic fillers*

Some reference must be made to a class of compositions which have found extensive uses in the chemical and allied industries by virtue of their excellent resistance to chemical attack. Such compositions are based upon phenolic resins, heavily filled with special grades of acid-washed asbestos and

other mineral fillers. They can be moulded into shape by the application of moderate pressures and caused to harden by heating. Hydraulic presses are not needed to provide the working pressures required, so that it is possible to produce quite large moulded articles by this process. Vats, tanks and other vessels used in the chemical industries are produced in this fashion. Materials of this type are manufactured in this country under the trade name "Keebush".

#### 2.2.6. *Fabrication of plastics by casting processes — cast films*

The development of the photographic industry was slowed up for many years for the lack of a tough, non-brittle, flexible carrier for the light sensitive silver emulsion. Glass was an excellent material, but it was heavy and brittle. It is quite evident that the cinema could never have been possible without the continuous flexible base, and just as it was the celluloid base film which laid the foundations of the cinema, so it was the moving picture industry which produced the incentive for the production of better and more stable films. It is interesting to note in passing that in spite of the large number of quite remarkable polymers available today the photographic industry still relies on the cellulose polymers. The pioneer celluloid has largely given place to triacetate, it is true, but still the cellulose chain literally carries the moving picture industry today, and there are no serious competitors in the offing.

The large-scale production of continuous film has developed by two rather different methods, known respectively as the wheel and the band method. Originally film base was cast on long glass tables; the Eastman Company using tables up to 200 ft. long, which was adequate for the early cine film. Apart from the limitations in length (it was not continuous) these early films had many other disadvantages, and were replaced in the first decade of this century by continuous casting on the surface of a large slowly rotating wheel. Such wheels, 15 ft. or even 18 ft. in diameter, and nearly 5 ft. wide, were eventually built, with polished surfaces of nickel or stainless steel, and capable of production of film either of cellulose nitrate or 'non-flam' cellulose acetate, continuously for very long periods. Plant such as this is still used in which the wheels themselves are jacketed — that is, there is an inner wheel concentric with the outer rim — and through the inter-space, water at a suitable temperature can be passed, entering and emerging centrally from the hub of the wheel. The heating of the solution or "dope" layer to evaporate the solvent is effected by means of an exterior jacket, also concentric with the wheel, and through which steam or hot water is passed, but the complete removal of the solvent is effected by a subsequent seasoning process and is not carried out on the surface of the wheel (Fig. 11).

It is only during the past 20 - 25 years that film manufacture has met with any commercial success in Britain, and until the last War production was confined to 'commercial' film — i.e. film used for packaging, colour cards, and other diverse uses.



During the War, however, nitro-film of photographic quality was first produced, and this success led eventually to the establishment of a large production unit making photographic film base for all purposes from cellulose triacetate. From the beginning band machines were employed in this country, and their manufacture was made possible by the production in Germany and Austria of endless bands, at first with a brazed joint but later with an invisible welded joint, and made of copper and later of nickel. They are made of considerable size — 28 metres of 92½ ft. long and 54 in. wide in a regular size, but much longer ones have been supplied. The technique of casting on a band machine is much the same as on a wheel, except that the solution is poured or 'cast' on to the gelatine coated surface of the metal band running horizontally round two end drums, instead of on to the surface of a wheel (Fig. 12).

The production of film by the alternative melt-casting is applied to crystalline types of polymer, such as nylon and terephthalic polyesters ('Terylene' or 'Dacron'). It depends on the fact that these polymers have comparatively sharp melting-points; above these temperatures they exist as viscous liquids, which can be extruded from a pressure spreader, either by a screw extruder or a metering pump. The process was first applied to nylon, where an extruder is employed to force the polymer through an adjustable slot, the hot extruded film being picked up by a chilled drum, after which it is longitudinally stretched by pulling rollers before reeling. A slightly different method has been described in patents for the production of polyester film, known in the U.S.A. as 'Mylar', and in Britain as 'Melinex'. This method is designed to avoid the separate preparation and remelting of the polymer, which is not only unnecessary, but undesirable, because of the danger of oxidation and consequent discolouration. The molten polymer is fed to a metering pump and then directly to an extrusion hopper, which spreads a thin uniform layer continuously over the surface of a casting wheel. The film is stripped and then passes through a cooling bath, after which it is stretched laterally by a tentering device and longitudinally by rollers in a heated section, and then finally into a setting and cooling zone before reeling. The two processes have the common feature of cooling, followed by stretching, the reason for this procedure being that quick cooling is necessary to prevent random crystallisation, with consequent opacity and brittleness, while subsequent stretching gives orientation of the molecules with crystallisation in preferred directions. In other words cooling gives amorphous material, strong enough to be processed, and orientation through stretching allows the intermolecular attractions which give crystallinity to develop the maximum strength of the material, which in the case of 'Mylar' film is extremely great. I shall refer to this general principle at some length later.

### 2.2.7. Casting solid units

Several plastics materials may be cast by processes which in some respects are analogous to the

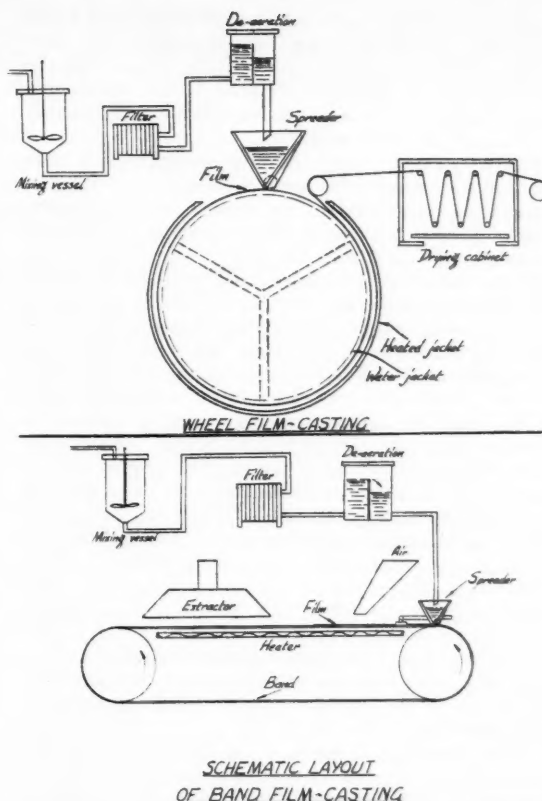


Fig. 11 (top). Diagrammatic layout of a wheel film casting plant, tracing the progress of the process from the mixing vessel through the casting machine to the finished roll.

Fig. 12 (bottom). Diagrammatic layout for a typical band casting process.

casting technique used with metals. Of the thermosetting materials, phenolic resins, urea formaldehyde resins to a lesser extent, as well as polyester and epoxide resins, may be cast in liquid form into suitable moulds where the curing reaction, by which they are converted to an infusible solid state, takes place. There are also one or two casting techniques specially suitable for use with thermoplastics materials. In the case of the thermosetting resins, the casting technique has in the past been applied to the production of decorative articles, particularly of special phenolic resins made from high purity reagents under controlled experimental conditions. The casting moulds may be of metal (lead) or of rubber or p.v.c., the design of the moulds being such as to allow for shrinkage of the order of 1%. The minimum wall thickness of  $\frac{1}{8}$  in. to  $\frac{3}{16}$  in. is recommended, but there is no limitation on the permissible wall thickness, provided the curing schedule is arranged so that the resin hardens uniformly throughout its mass. The casting technique is still applied to phenolics, but it is rarely used with urea formaldehyde resins because of their

higher shrinkage, although it is of interest to recall that the initial idea for the production of these materials was to provide a substitute "glass" for the production of lighting pendants, a use which was terminated by the internal stress so readily developed by these materials.

Polyester resins containing mineral fillers in fibre or powder form are used in small quantities in casting applications for the repair of metal parts, although they are not as satisfactory as the epoxide resins in this respect. The latter class have much greater adhesion to metals and very much lower shrinkage during cure. The epoxide resins are indeed a versatile class, possessing remarkable adhesion to metals, glass, wood, in fact, to most materials. Normally obtained in liquid form for casting applications, they are converted to an infusible cross-linked state by the addition of a curing agent. The curing characteristics as regards speed, temperature sensitivity, and degree of hardness developed can be varied to a considerable extent by selection of appropriate curing agents. Fillers can be incorporated to modify the properties and to give an appearance simulating metals or porcelain. Well publicised for their usefulness in paints and adhesives, the epoxide resins will find their largest outlets in the engineering trades in an ever-increasing range of applications, including filling and upgrading porous metal castings, repair work in the gas industry and repairing cracks in concrete and masonry.

The casting technique applied to methyl methacrylate is well known for the embedding of biological and botanical specimens. The addition of a peroxide catalyst to the mobile water-white monomer, methyl methacrylate, or syrupy partial polymer thereof, will initiate rapid conversion to a crystal-clear hard product. A modification of this known as the "slush" moulding technique has also been used in connection with certain cold-curing phenolic resins, but is more suitable for the production of fairly small articles from a p.v.c. (polyvinyl chloride) paste. Certain grades of p.v.c. can be stirred into an approximately equal amount of plasticiser to form a free-flowing paste which gels when heated to a temperature in excess of 140°C. The procedure followed in a slush moulding is to charge an amount of p.v.c. paste to a previously heated hollow mould, e.g. for the production of a doll's head, slushing the compound around so that it

forms a skin on the wall of the mould. Excess paste is drained off and the mould passed through an oven to complete the gelation to a relatively soft, flexible product.

#### 2.2.8. Calendered sheet (free and supported)

In the calendering process the plastics material, in the form of a warm doughy mass, is passed between a series of three or four heated rollers in which it is thoroughly worked and homogeneous. It emerges from the rolls in the form of a flat film or sheet, the gap between the last pair of rolls determining the final thickness and uniformity. Several types of roll arrangement are available, those of the 'Z' and inverted 'L' types being standard in the industry. Usually calenders are designed so that thin films and heavy sheeting can be produced alternatively on the same equipment, which means that the rolls will be subjected to a wide range of separating forces which tend to bend them. In order to keep the sheet flat, either the technique of roll bending, when an opposing bending moment is applied to the rolls, or the technique of roll crossing, when one roll axis is crossed slightly with respect to the other, is employed. When required, the sheet may be embossed to give a variety of attractive surface patterns by means of a special unit placed between the calender and the cooling rolls. The current trend is towards double or turret type embossing units in order to provide a quick change of pattern. The cooling rolls are usually driven in groups of three for best speed control, the number required depending on the sheet thickness and the production rate. A high speed sheeting calender may require nine or more cooling rolls.

Calendering can also be used to apply a covering to such backing materials as paper, fabric, etc. The film and backing material are simply squeezed together between the heated rollers so that they emerge as a completely united sandwich.

#### 2.2.9. Expanded plastics

In the last few years expanded plastics have attained considerable importance, initially mainly as thermal insulants, but more recently as structural materials, either alone or supported in sandwich form with sheets of rigid plastics. These expanded materials fall into two broad classes accordingly as the cellular structure is open or closed. Within this general classification are many different types, but

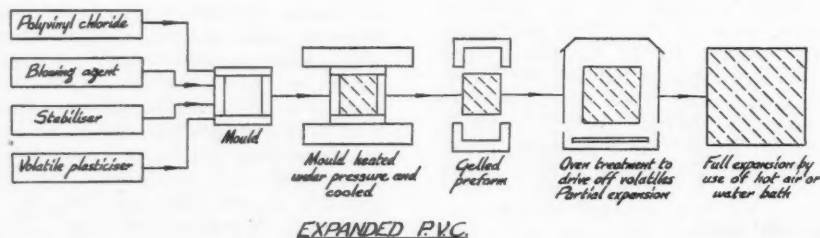


Fig. 13. Diagrammatic representation of the production of expanded p.v.c.

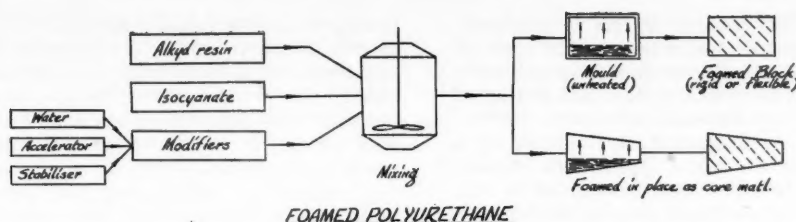


Fig. 14. Diagrammatic representation of foamed polyurethane.

although theoretically any plastics material (thermo-plastic or thermosetting) can be expanded, very few individual plastics are thus worked today on any significant commercial scale. Today the most important are p.v.c., polystyrene and polyurethane, but it is almost certain that with the increasing appreciation of the remarkable properties of expanded plastics, other members of the plastics family will be added to those now being worked commercially. In view of the actual and potential importance of these materials, I think a brief reference should be made to the more important members (Fig. 13 and 14).

#### 2.2.9.1. Closed-cell expanded p.v.c.

Closed-cell expanded p.v.c., which may be either rigid or flexible, is produced by mixing the p.v.c. resin with a chemical blowing agent such as azoisobutyronitrile (A.Z.D.N. or Porofoor N), a plasticiser if the flexible grade is required, and colourants, stabilisers, etc. The composition is loaded into a mould the cavity of which represents a small replica of the desired expanded article. The mould is completely filled, sealed with an efficient gasket and then heated to about 160°C. In this stage, the blowing agent decomposes and the p.v.c. is gelled. Locking pressures of the order of 2 tons per sq. in. are needed to keep the mould closed against the internal pressure developed. After heating under pressure for a period determined by the dimensions of the mould, heating is stopped and the mould is cooled rapidly while maintaining the pressure. When cold, the "blank" is extracted from the mould and heated at a moderate temperature, 70°C - 100°C; in this stage the p.v.c. softens and the gas contained in it causes it to expand to its full size. Densities as low as 2 lb. per cu. ft. have been obtained by this method.

#### 2.2.9.2. Open-cell flexible p.v.c.

Two continuous processes have been developed in America for the manufacture of open-cell flexible expanded p.v.c. One of these employs a p.v.c. paste which is saturated with an inert gas, such as carbon dioxide, under pressure while refrigerating the composition. The gassed paste then passes to a spraying head where it is discharged on to a conveyor belt, foaming as the pressure is released. The foam is levelled by passage under a doctor blade and then passed between the electrodes of a high-frequency

generator, where further expansion takes place and the p.v.c. is gelled. A speed of production of 18 in. per minute for foam 2 in. thick has been quoted for this process.

The other process utilises a p.v.c. paste in which is dispersed a chemical blowing agent. The paste is distributed on a conveyor and passed in succession first through a heating zone which decomposes the blowing agent and allows foaming to take place, and then through a zone at higher temperature where the resin is gelled. The second heating stage is usually accomplished by means of high-frequency heating.

#### 2.2.9.3. Polyurethane foam

In contrast to cellular p.v.c., polyurethane foam is "self-expanding". The reactants are, basically, an alkyd resin, a polyisocyanate and water. On mixing these materials together a complex chemical reaction ensues; the polyisocyanate reacts with hydroxyl and carboxyl groups in the alkyd resin, in the latter case producing carbon dioxide, and also with the water present, again producing carbon dioxide. The net result is that the composition cures and is simultaneously foamed by the liberated gas. The rates of the two reactions have to be balanced against one another in order that the gel point is reached at about the point of maximum expansion.

Flexible foam, which is now beginning to find a variety of applications, such as in upholstery, insulated clothing, etc., is most economically produced by continuous processes, a typical example of such a process being as follows. A comparatively small mixing chamber is mounted directly above a conveyor system which carries a series of box-shaped moulds. The mixing chamber is mounted in such a way that it can be automatically traversed from side to side of the conveyor. The reactants, alkyd resin, polyisocyanate and modifying agents are fed to the mixing head by metering pumps, mixing takes place within a few seconds and the mixture is continuously discharged to the mould moving below. The traversing movement of the mixing head ensures that a reasonably uniform "fill" of the mould is obtained. Foaming commences almost immediately the mixture is deposited in the mould and, after travelling a short distance on the conveyor during which period the foam reaches its maximum height, it enters a heated zone where the reactions are completed. On emergence from the heated zone, and after cooling, the foam can be slit to the required thickness.



Control of all the variable factors is absolutely essential for successful operation of this type of process. Temperatures and viscosities must be closely watched, and laboratory supervision and testing of the raw materials is continuously necessary.

Rigid polyurethane foams can be produced by a similar process, but the main applications of such foams stem from their ability to be foamed *in situ*. Such foams are used for filling cavities, for example in aircraft wings, and confer rigidity upon such structures without a great increase in weight. To prepare such foams, the necessary quantities of reactants are weighed, mixed together and the mixture immediately poured into the cavity. Foaming ensues and the mixture rises to fill the cavity and then sets to the rigid state. Owing to the good adhesive properties of the polyurethanes, the foam adheres strongly to the surfaces of the cavity. Light-weight sandwich panels can be made in a similar fashion by casting the foam between sheets of aluminium, fibreglass reinforced plastics, etc.

#### 2.2.9.4. Expanded polystyrene

The raw material for the production of expanded polystyrene consists of polystyrene beads, prepared by suspension polymerisation, which are impregnated under pressure with a gas and/or a volatile liquid. To prepare moulded blocks of expanded polystyrene, such expandable beads are first pre-expanded by heating them in a bath of hot water. The pre-expanded beads, which are now many times their original size, are then allowed to stand for 12 to 24 hours to allow them to come to equilibrium with the atmosphere. They are then loaded, in calculated weight, to a perforated closed mould which is heated by steam or by immersion in hot water. The beads expand further, filling the mould completely and forming a strong coherent moulding.

In another process, which is not at present operated in this country, expanded polystyrene of a different type is produced. Polystyrene beads are impregnated with a volatile material, and then fed to a screw extruder. On emergence from the extruder nozzle, the polystyrene expands. This process is useful for the manufacture of expanded polystyrene in long lengths of sections such as boards, rods, etc., which can be extruded, but if other shapes are required, they must be machined from the primary material.

### 2.3. The fabrication of plastics by the application of pressure or vacuum

In some ways plastics have the advantage over metals from the point of view of fabrication in that, being more temperature-sensitive, they can be more easily formed by the application of force aided by temperature. Thus, whilst except in limited instances metals cannot be formed by what may be described as the "push and pull" methods using air as the medium, thermoplastics when suitably heated can be readily formed by the use of air pressure or of vacuum. In both cases the processes are logical in principle and simple in operation; indeed, blow moulding is almost as old as the industry itself,

having been traditionally applied to the formation of such common articles as celluloid dolls and ducks which most of us know from our childhood. Strangely enough the reverse process, though equally obvious, has only been explored on any scale during the post-War years, but since then great strides have been made in this vacuum-forming or suction-forming, as it is sometimes called, and the process appears destined for considerable extension in the near future.

#### 2.3.1. Blow moulding of plastics

The process of blow moulding plastics materials has a long history, having been applied for many years, principally to celluloid sheets and tubes. Two celluloid sheets are clamped within a die and steam is blown between them in such a way as to do the double job of softening the material and forcing it against the die where it is subsequently cooled. Along the edges of the cavity, lands on either mould-half nip the two sheets together to form a welded seam. For this method of operation the die has to be heated and cooled and the material requires to be pre-formed. While use of this method continues in restricted and specialised applications there has been a marked reduction in its general employment, particularly since celluloid has fallen from favour for the production of toys.

More recently there has been rapid development of methods in which the preformed material is actually produced as part of the process, and the heat therein at this preforming stage used for further manipulation. Employing either injection or extrusion machines as the motivating power a number of methods have been developed for the manufacture of holloware — principally bottles — employing a relatively small range of materials, and in particular low density and high density polythene, and nylon.

In essence the modern process of blow moulding consists of forming a tube (not necessarily circular in section) and by the internal application of air pressure, while the tube is within a mould cavity and is still sufficiently heated, blowing or forming the material against the cooled mould walls where the article cools and can be removed by opening the mould at the correct instant. The methods by which hollow articles are made can be differentiated as :-

1. Those based on an injection machine :
  - (a) forming a closed ended tube for subsequent blowing in a separate cavity;
  - (b) forming an open ended tube, closing a mould around it and blowing on the machine;
  - (c) forming without a base, which is later welded in (this is not blow moulding).
2. Those based on an extrusion machine :
  - (a) single tubular parison with fixed nozzle attached to mandrel and single die;
  - (b) multiple parisons with similar nozzles and rotating feed;
  - (c) single parison with rotary die assembly.

The extruder-based methods can be classified according to the relative positions of extrusion die



and blowing nozzle, since the nozzle can come through the mandrel of the extrusion head (B.P. 516,262), or be opposed to the mandrel (B.P. 697,326, B.P. 713,419). Something like 16 British patents cover the various aspect of the process. Some idea of the general operation of the process is given in Fig. 15.

For 'squeeze' and other types of bottles for cosmetic applications and for chemical bottles where impact resistance is important the two main types of polythene are employed. For applications where improved heat resistance is required the higher density grade of polythene is frequently employed. Various grades of nylon — either copolymers or special high molecular weight grades of the straight polyamides — offer the advantages of improved transparency, combined with good heat resistance and toughness; pharmaceutical applications might be mentioned in this connection.

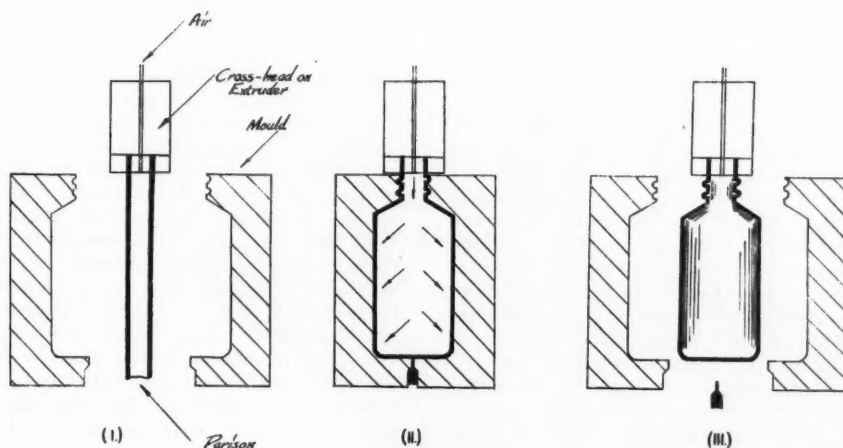
### 2.3.2. The vacuum forming of plastics

The vacuum forming process provides a simple rapid-cycle method of forming thermoplastic sheets by means of heat and a combination of vacuum and atmospheric pressure. It is a technique that is particularly suitable for the forming of sheets of styrene co-polymers and vinyl co-polymers; ordinary polythene does not possess the right combination of mechanical and thermal properties for successful manipulation by the vacuum forming technique. The largest material consumption in vacuum techniques is of toughened polystyrene, but use is also made of

polyvinyl chloride, polyvinyl chloride copolymer, high density polythene and cellulose acetate sheet. Of particular interest, since they are just beginning to be employed in this country, are the A.B.S. copolymers (based on styrene-butadiene-acrylonitrile) which combine extreme toughness with good handling characteristics.

In essence the process consists of clamping the plastic sheet in a frame, applying heat to soften the sheet and then evacuating the air from between the sheet and a mould so that atmospheric pressure forces the softened sheet against the mould. When sufficiently cool, the formed sheet is removed. Methods of heating by steam, hot water, hot oil and infra red lamps have been discarded as being either too slow, or giving uneven heating; most commercial machines employ heaters using electrical resistance wire in some form. In fact, the development of accurately controllable high temperature heaters has been a major factor in the recent rapid growth of this method of fabrication.

The variables of heating, cooling and forming require control. In automatic machines the various stages are controlled sequentially, following one another in quick succession. Each stage must be completed before the following operation can start. Should the heating stage be time-controlled, this part of the cycle should be reproducible to within one-fifth of a second. While pressures in vacuum forming are relatively low (14 lb./sq. in. or less) it must not be overlooked that the total pressure exerted on a large mould can run to high values. Thus, for example, when using a mould 6 ft.  $\times$  4 ft., a pressure of



### BLOW MOULDING

Fig. 15. Diagrammatic representation of the blow-moulding of a bottle: PART I shows the extrusion of the plastic tube or parison into the open mould. PART II shows the mould closed, thereby closing the end of the tube, the extruded plastic mass being forced by air pressure to take the contour of the mould. The final stage of the process is shown in PART III, with the mould once again open and the finished bottle ready to be severed from the parent tube.

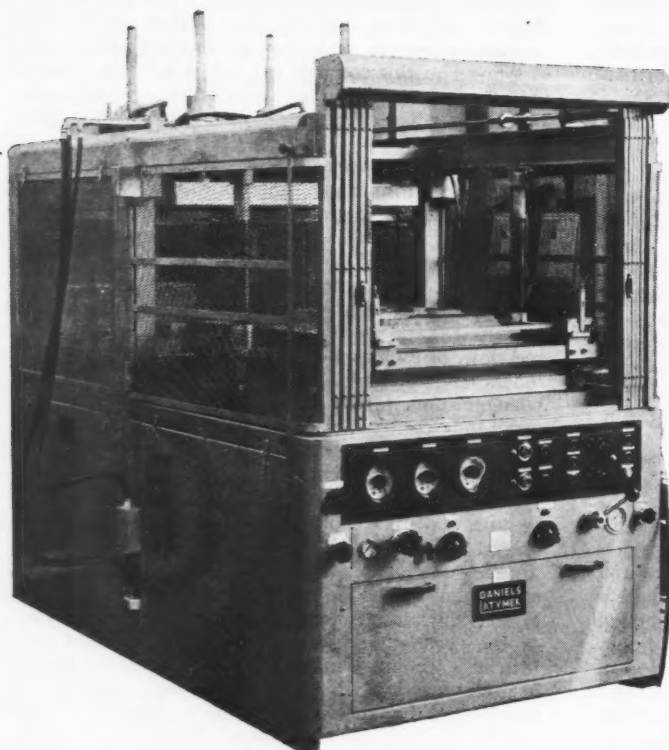


Fig. 16(a).  
Commercial vacuum forming machine.  
(Courtesy of Alfred Herbert Ltd.)

48,000 lb. is imposed on the sheet and also on the machine table, which must be sufficiently strong to withstand this sudden load.

Even such an apparently simple process has its 'snags'. The forming operation in stretching the sheet must, of course, reduce the sheet thickness. The stretching is localised at those parts where the sheet is drawn, but the major cause of thinning is the way a sheet clings (or 'blocks') to the walls of the cavity. Yet at no point must the thickness be so reduced that the sheet ruptures during forming under the combination of heat and pressure, nor must the product be flimsy. The simplest vacuum forming technique, in which vacuum alone is used to pull a heated sheet into or over a mould, is suitable only for the production of articles of shallow draw, since the deeper the cavity the thinner will be the plastic form. A rule of thumb generally used is that "straight" vacuum is not used where the diameter of an opening is less than twice the depth. By decorating flat sheets in a distorted pattern by silk screen printing, articles with highly accurate decorations may be produced inexpensively by the vacuum forming technique.

A variation of straight vacuum forming, in which a male form is placed in a cavity, gives a stronger article since it leaves the thickest part of the sheet on the top. However, much more waste occurs with this method because the sheet must be drawn down the sides of the female portion of the mould

sufficiently far to prevent excess thinning at the base of the male plug. The technique has been recently largely replaced by "drape" forming, which has the advantage of producing thick-walled sections without extreme waste. In this modification of the vacuum forming technique, the plastics sheet is draped or pulled over the male form until the level of the sheet is down to the lowest height of the mould. The sheet is then sealed at the edges and the vacuum applied, pulling the sheet to the contours of the mould.

One of the most economical processes is vacuum forming the hot sheet as it emerges from the die of a sheet extruder. The proponents of this technique emphasise that all scrap can be reground and fed back into the hopper of the extrusion machine. This principle is, of course, made use of in the 'blow' moulding of hollow bodies already described and it has the advantage that not only is the expensive process heat conserved, but the plastics material suffers less structural degradation (see Figs. 16(a) and 16(b)).

Many other variants of the vacuum forming technique have been described in a search for a reliable method for deep forming with more uniform thickness. In the 'plug-assist' forming technique a wooden plug, only slightly smaller than the female mould, is employed to form the heated sheet. The air, trapped in the cavity as the plug descends, forces the sheet against the plug and keeps it away from the cavity walls, particularly at the rim. The air pressure is

maintained until the end of the plug stroke, when vacuum is applied to form the sheet against the cavity wall. Plug-assist forming employs a combination of drape action and the effect of the trapped air to keep the material away from the cavity rim so as to reduce blocking to a greater extent than does drape-forming. Thickness data obtained from trials in which various factors were varied has shown that the plug should closely approach the size of cavity and that the air pressure is a critical factor<sup>9</sup>. Blocking has also been reduced by an 'air slip' process in which air is again trapped, but now between the plug and the sheet. The trapped air forms the sheet into a bubble which the plug reaches towards the end of the stroke. The air is evacuated and the sheet is formed against the plug without a female die. It has been claimed that this method allows control of the uniformity of thickness to within 10%.

The latest improved technique is known as the Dropform method which combines the idea of an assisting plug with the drape and Airslip technique<sup>10</sup>. This versatile combination has been designed into different styles of machine according to the end use, whether it is large industrial mouldings or rapidly produced thin-wall disposable containers. It is interesting to note that, at what might be called extremes of use, the sheet-forming techniques are in competition with, respectively, the largest injection machines and the fast fully automatic smaller machines. This is something like the completion of a cycle of events.

As in the case of injection moulding and extrusion moulding the vacuum forming technique, although in principle so simple, has been found from experience to be dependent for successful operation as a

production technique upon careful control of all the relevant factors. This emphasises again what is so often overlooked by those without previous experience of plastics materials, that they are man-made high molecular weight chemicals whose properties depend upon their chemical structure, and these properties will inevitably be impaired by any fabricating method which degrades or adversely influences this optimum chemical structure. This again is a point on which I shall have more to say later, since it is the point which possibly more than any other draws the distinction between fabrication methods as applied to plastics and metals.

## 2.4. 'Working' plastics 11-15

### 2.4.1. Machining of plastics

Where it is necessary to machine plastics materials either for assembly or decorative purposes, the conventional techniques and tools used in the metal industry can, broadly speaking, be employed. In metal-working certain recommended conditions, such as cutting angles, speed of cutting, etc., must be adhered to if a high and accurate standard of work is to be achieved, and similar recommendations exist for the machining of plastics. Due to the large number of plastics materials commercially available today, and particularly in view of the fact that no two types of materials will have identical physical properties, it is not possible to generalise when talking of the fundamental differences between the working of metals and plastics. Considerable data have now been published on the subject, and optimum machining conditions for almost every class of material have been carefully worked out and documented.

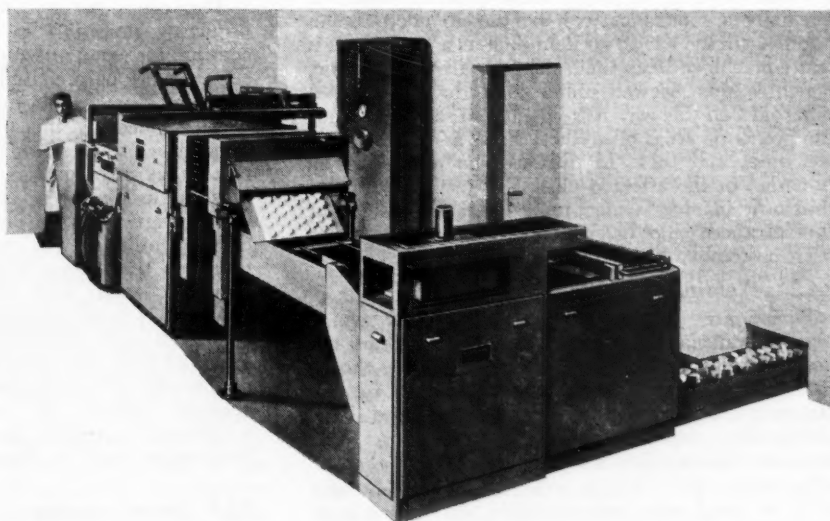


Fig. 16(b). General view of "Formvac" automatic production line for plastics containers and lids.

(Courtesy of Hydro-Chemie, Zürich)

In the working of plastics a number of points must be borne in mind, in particular the following :-

1. That the majority of plastics have a relatively low softening point, and this, coupled with their poor thermal condition, may lead to burning, distortion or discoloration if the machining limits and conditions are not rigorously observed.
2. That in many instances plastics are significantly brittle and may exhibit internal stress so that chipping or breaking may occur when a mechanical shock is applied as, for example, in a punching or even turning operation.
3. The swarf from cutting may, due to the nature of the material, be powdery and so lead to clogging or binding of a drill or tap.

The golden rule to be applied in working plastics is to maintain an extremely sharp cutting edge, and this may mean frequent sharpening of the tool. In addition it must be remembered that many plastics, particularly those containing mineral fillers such as silica or slate powder, or reinforced with glass fibres, are very abrasive. The majority of plastics can be machined without the use of a lubricant, but in the case of some thermoplastics it may be preferable to apply soluble oil and water or a soap solution, or even paraffin wax, to the cutting face. An air jet assists in the removal of swarf and dust, and at the same time is a valuable aid to dissipating some of the heat evolved. Where metals and plastics are to be used in conjunction with one another, i.e. in threading or tapping plastics to fit a metal bolt or nut, allowance should be made for the difference in thermal expansion of the two materials and such combinations are to be avoided altogether if the operating temperature of the assembly is extreme.

In passing it should be mentioned that this internal physical stress in some plastics, which is normally a hindrance, can be put to good use in photoelasticity, where an item such as a gear wheel is firstly machined from the clear stress-free cast plastic, which is then viewed under load through crossed polaroids. In this way it is possible to see at a glance the points or areas of greatest stress and consequent weakness, and these in turn can be minimised by re-design of the affected part. The whole procedure thus only involves a machining operation instead of the advanced and lengthy mathematics which has been customary hitherto.

#### 2.4.2. Welding of plastics 16-22

There are a number of techniques by which plastics materials can be joined together without the use of solvents or cements, the actual method chosen in a particular instance being dependent on the characteristics of the material and the size and shape and general requirements of the application. The methods can be classified as follows :-

- (a) *Welding* — which is something closely akin to metal techniques in that a filler rod is used. However, since the electric arc method of providing the localised heating cannot be applied to a non-conductive material, the source of heat must be a stream of hot gas which is

controlled and directed by the use of specially designed torches, and to avoid oxidation of the plastics material, inert gases (nitrogen is usual) are employed. A V-shaped gap is made by cutting or machining the edges of two sheets and a filler rod is gently pressed into the gap as both edges and rod are heated. As with metal welding, considerable skill and experience is necessary to avoid the pitfalls of poor joints with risk of stress cracking. This latter point becomes of special importance where certain environmental conditions arise, for example with polythene, which in most of its fabricated forms, and unless high molecular weight grades are employed, is prone to 'environmental cracking'. Polythene and rigid p.v.c. are the materials most frequently fabricated by this technique and chemical plant ducting and tank liners are common applications.

- (b) *Butt welding*. For joining rods and tubes, welding can be accomplished by butting molten ends together. The softening is produced by use of radiant heat, and pressure with a slight twisting action serves to make the weld. About 70% tensile strength is obtained by this technique.
- (c) *Heating sealing*. Thinner materials such as film or foil are welded by heating and pressing two layers together along lines about  $\frac{1}{16}$  in. to  $\frac{1}{8}$  in. wide, and this technique is used in making bags or sachets of polythene layflat tubing. To prevent adhesion to the heated presser jaws a coating of p.t.f.e. or a p.t.f.e. film is used. The mechanical strength of such a joint is not very high.

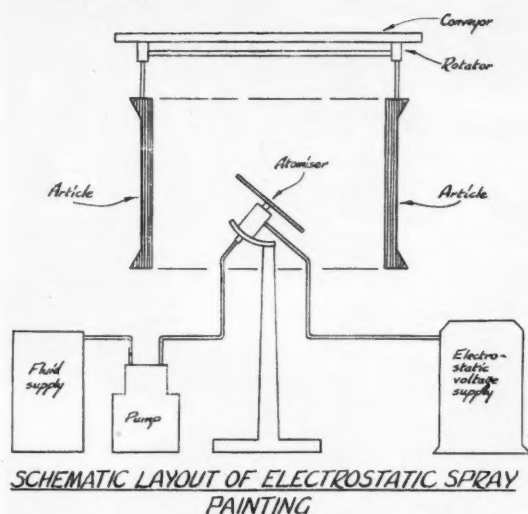
#### 2.5. Plastics coatings and adhesives

The origin of the idea of applying naturally occurring materials as protective and decorative coatings for wood and metal is lost in antiquity; most certainly it long predated plastics. It is not surprising, therefore, that as plastics became commercial they were applied as the natural polymers had been applied before them, as their protective layers. First came the nitro-lacquers in the 20's, the 'cellulose finishes' as they were and still are called, followed by contrast with the phenolics and alkyds, the so-called synthetics. For many years it must not be forgotten that alkyds topped the production lists in polymers, and even today they account for 464,915,674 lb. of America's gigantic polymer totals, compared with 482,883,073 lb. for phenolics and 148,112,637 lb. for cellulose. Whether 'cellulose' or 'synthetics', polymers have done and still do yeoman service in protecting and decorating traditional materials, and add considerably to the production total of plastics.

##### 2.5.1. Spray coating

The traditional method of applying spray coatings remains as it started — the spray "gun". In special lines the application of emulsions by brush, roller and spray, has increased in recent years, although





**Fig. 17.** Diagrammatic layout of the Ransberg electrostatic spray painting process.

this applies more particularly to the so-called plastics emulsion paints which are based on polyvinyl acetate, and are the joy of the home decorator housewife who can wield her roller applicator to good purpose. Notable also are the p.t.f.e. emulsions which are now becoming widely used; the initial spray coating, being followed by the high temperature sinter-stoving, give coatings which are not only protective, but have frictional properties equal to an ice/ice surface. For the rest the field is with the solution spray guns which, though improved in detail, are basically similar to those with which the industry was founded.

A variant of the solvent-vehicle / air-current atomisation process, and one which has attained considerable significance for high quality work in recent years, is the so-called electrostatic spray method, in which the lacquer or paint medium is formed into droplets by spinning from a disc, and these droplets are attracted to the surface of application within and by reason of a high electrostatic field, rather than, as is conventional, being forced thereon by the application of air-jet pressure. A process of this type has been widely developed under the Ransberg patents and is diagrammatically illustrated in Fig. 17. Articles to be coated are earthed through their hangers and are moved automatically and continuously into the coating chamber. Here a voltage pack is connected to the disc or bell-shaped atomiser, creating an electrostatic field between it and the articles to be coated. The lacquer is fed to the atomiser and the atomised particles fly direct to the article by reason of the electric charge they carry. The inevitable result is that every droplet of lacquer must eventually find its way on to the target area, which is the article to be coated, so that little or no waste can be experienced. Not only does this mean

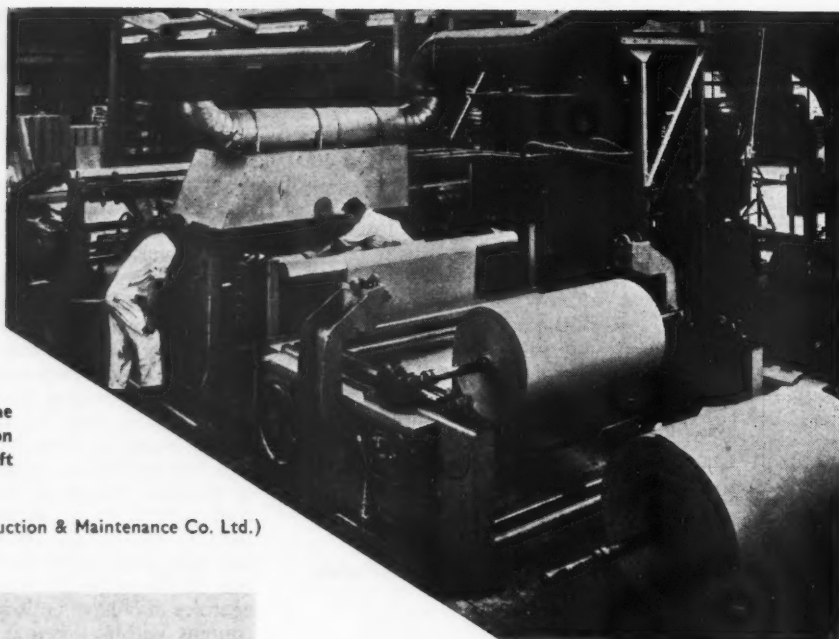
that the lacquer is 100% used, but there is in consequence no 'overspray' to be exhausted. The method claims a high degree of performance and is independent of the personal factor and skill of the operator. Some idea of the efficiency claimed for the process can be obtained by an example cited, in which for a particular article the introduction of electrostatic in place of conventional spray gun painting cut the rejects by 90% and stepped up production from 1,200 pieces/8-hour shift to 1,000 pieces/hour.

Another variant of spray coating of particular interest to engineers is that known as 'cocoon' coating, pioneered in America and operated in this country by R. A. Brand. As the name implies, the process aims at enclosing or cocooning an article rather than coating its surface in a conventional manner, and may be applied to almost anything from a small machine tool to a battleship. A special gun first applies a 'spider web' over the extremities of the unit, and on to this base a continuous flexible coat is then built. When solvent free the coating tightens completely enclosing the article. Some of you may have seen the Princess flying boat at the Isle of Wight which was coated in this way. The coatings may have built in 'zips', so that the moisture content within the unit can be controlled or the coatings may be removed at will. This method for the production of tailor-made tough and flexible coatings for large and small plant should be of great interest to engineers.

### 2.5.2. Flame-spray coating

Yet another variant of the spray coating technique is the one in which the finely divided plastics material is rendered fluid by being projected at high speed through a hot flame, and whilst in this state is forced by an air stream on to the surface to be coated, where it is further heated so causing all the particles to coalesce to give a uniformly smooth surface. Among the earliest of these was the Schori process, originally developed for the flame-spraying of relatively low melting metals, but now for some years used successfully for applying a number of plastic and related materials, particularly as protective coatings. The process uses as its raw material a fine plastics powder of particle size around 60 mesh, which is carried in a flow of air through the inner nozzle of a specially designed gun. An annular nozzle concentric with the powder nozzle carries an oxygen/propane mixture which is ignited to give a high temperature flame. A further annular nozzle around this carries a stream of air alone which serves to control the heating of the oxypropane flame (Fig. 18).

In practice the surface to be coated is preheated and this may simply and effectively be achieved by use of the gun without the powder being fed through it. The surfaces to be coated should be free from dirt and oily contamination and, if metal, should preferably be shot-blasted or treated by some similar process to give a good keying medium. When the surface has been preheated to a suitable temperature, the powder is fed through the oxypropane



**Fig. 19.** General view of the Telcon plant for extrusion coating of polythene on to kraft paper.

(Courtesy of Telegraph Construction & Maintenance Co. Ltd.)



**Fig. 18.** Spray gun.

(Courtesy of the Schori Division of F. W. Berk & Co. Ltd.)

flame, and conditions adjusted to give a molten coating on the substrate without decomposition. After the desired thickness has been built up it is sometimes an advantage to moderate the flame to a low temperature luminous type, cut off the powder supply, and carefully 'flame' down the coating to give complete fusion of the top surface. The process is necessarily limited to materials of reasonable thermal stability with decomposition temperatures sufficiently remote from their softening points. To facilitate this, the gun used for flame-spraying is a slightly modified design compared with that normally employed for metal work. The following materials in particular may be used in the process: polythene, nylon, shellac/mica, thiokol, Araldite.

### 2.5.3. *Roller, extrusion, 'doctor' knife and dip coating*

From the earliest days of the use of plastics, it has been customary to apply them by methods which had been developed for the application of thin layers, many of which stemmed from the photographic industry. These involved the use of one or more rollers, the plastic solution or emulsion being applied thereto in an even stream which was to be distributed over the paper or fabric surface in a layer of uniform density. The coated material was then passed festoon-wise through a drying tunnel to remove the volatile solvent or aqueous medium. With the advent of melt plastics their application in solution form lost some of its popularity. It was found more advantageous to extrude the plastic into the carrying base of paper or fabric in the form of a fairly thick 'curtain', which would immediately adhere to the carrying base and form a uniform layer on cooling. Where thin coatings are required

it is customary to extrude at greater thickness, e.g. 10 mils, but to traverse the carrying base at such a speed that the layer is drawn out to one-tenth of its thickness (i.e. finished 1 in.) as it falls on and becomes attached to the carrier base. Plant of this type which is used by Telcon for coating craft paper with polythene for the production of cement bags and the like, is illustrated in Fig. 19.

Where thicker coatings are required, as in the production of the so-called 'American' or synthetic leather, it has been customary to apply the nitrocellulose or similar composition by means of a spreading knife or 'doctor' blade. The composition to be applied is usually fed into the 'V' which the blade forms with the fabric to be coated, the thickness of the coating being controlled by the downward thrust of the blade against the fabric. Since the growing popularity of p.v.c. has tended to take business away from nitrocellulose, the trend has been away from 'doctor' knife towards coating on calender rolls, as already described.

For coatings which completely or substantially encapsulate the unit to be coated simple dipping is resorted to. This needs very little special in the way of plant beyond a container for the solution or plastics melt, a conveyor belt to track the article into and away from the solution, followed by a drying chamber to remove any volatile solvent where this is used. This process has been applied to the coating of handles of electrical pliers, coat hanger hooks and such like small articles, which are of simple contour and free from re-entrant angles. Plastics of the type known as 'peel-coats', such as ethyl cellulose compositions, which are used to protect small machine tools for delivery in factory-fresh condition, are applied in this way.

#### 2.5.4. Fluidised solid coating

An interesting method of applying plastics coatings, which has increased in importance during the past few years, is known as fluidised solid coating. This is a dipping process in which the plastics material is actually applied in solid form, but the solid is so finely divided that it behaves like a liquid. This can readily be obtained if the solid particles are not only very small but are separated by air spaces. The process has been mainly developed with reference to the application of polythene and polyamides (nylon).

The prerequisite of the process is that the plastics material is available as a very fine powder and this is contained in a vessel capable of taking the largest unit to be dipped. The bottom of the container is a porous tile through which air under pressure can be forced to percolate. This vessel is half-filled with the plastics powder and the air is forced upwards through it so that it actually almost doubles in volume. The result is the equivalent of an ultra-light powder, into which the unit to be coated can be easily and completely plunged. Before this is done, the unit is uniformly heated to a temperature approaching the melting point of the plastics to be coated, so that when it is withdrawn it takes with it a perfectly uniform coating of finely divided plastic.

From the dipping vessel the unit next passes to the sintering oven, where the coating is melted to form a continuous layer over the surface of the article. The method is covered by patents<sup>23</sup>, and it has gained considerable popularity for the coating of intricate articles with specific plastics.

### 3. PLASTICS CONSIDERED AS ENGINEERING MATERIALS

#### 3.1. How different are plastics?

It is possibly because plastics emerged gradually and unobtrusively over a long period, and that they were known to be products of the test tube, that for many years engineers refused to take them seriously. To the man brought up in the traditions of iron and steel this was reasonable enough perhaps; how could he expect these pseudo-chemicals to do the man-sized jobs he was accustomed to put on to steel, copper and brass? Fortunately some branches of engineering were exceptions to this rule; indeed, plastics owe much of their development to the progressive outlook of electrical companies. To some extent the War changed the oppositional attitude and gave plastics their chance to show what they could do, and in the main they used this to good purpose. What they did show was perhaps surprising to the engineer, and it was not that plastics would sweep away all the conventional materials, but rather that they would aid the conventional materials to do jobs more efficiently or indeed, those jobs which they had never been able to do before. When engineers found that they were rather the natural friends than the enemy of plastics, the whole pattern of development changed, and from refusing to have anything to do with plastics or having as little as possible contact therewith, some engineers have taken a keen interest in the new materials, and have actually collaborated with plastics-producing organisations to develop materials to meet specific purposes.

The extent of the change which has taken place in recent years is, I think, epitomised in the opening paragraph of an interesting book on plastics recently published in America, and written by a Professor of Chemical Engineering, Gilbert Ford Kinney<sup>24</sup>. He writes: "Plastics are the wonder engineering materials of the modern age, provided they are properly employed. They have performance possibilities matched by nothing else, but to obtain them may require a special design. Thus they pose a problem for the practical engineer." This emphasises quite definitely that plastics are different; we shall learn that they are different among themselves and different as compared with traditional materials. The differences in conventional materials one from the other we know and rather take for granted because we have grown up with them, so why should we not accord the same consideration to plastics? Yet until relatively recently this was not done. To many engineers plastics were plastics, a group without individuality; that the individual members differed from one another as much as lead from platinum was for a time of little consequence. Now this has changed, and industry and the general public today



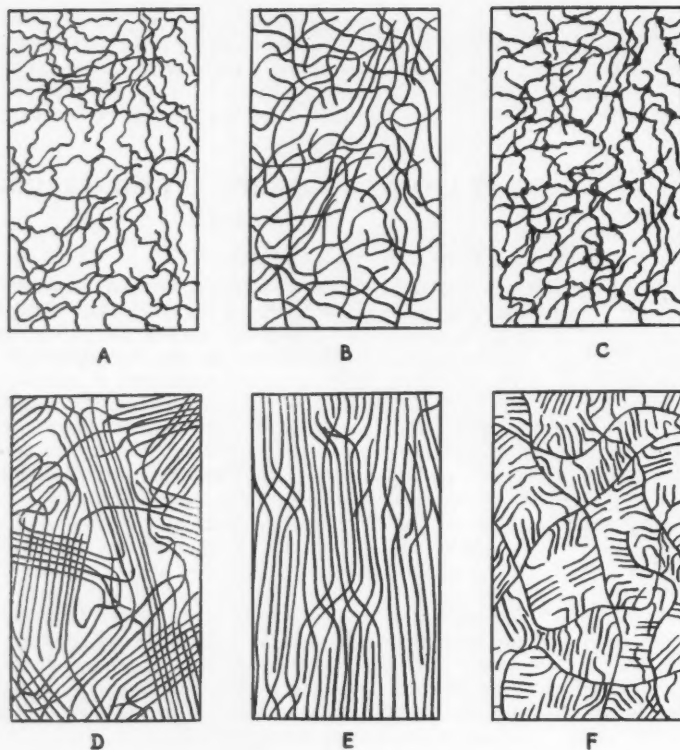


Fig. 20. Molecular aggregation, as suggested by Dr. Swallow.

#### STATES OF AGGREGATION OF POLYMERS

think not so much of the family of plastics as of individual members. The children of today are growing up with polythene and 'vinyl', as we grew up to know iron and steel, silver and gold. A brief consideration of some of these differences may help us to appreciate not only how plastics can best be used *per se*, but how they may with advantage co-function with traditional materials.

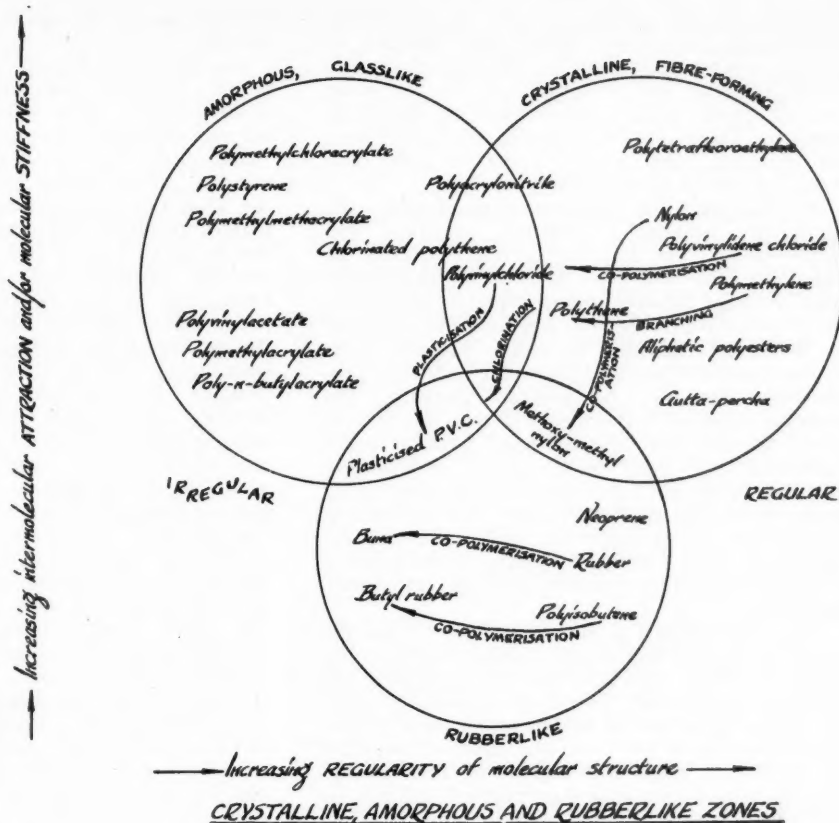
As I have already mentioned, plastics are chemicals, in the main, organic chemicals; from this fact stem most of their virtues and not a few of their troubles. Their outstanding characteristic is perhaps their molecular complexity; they are the materials of the giant chain-like molecules, and contrast significantly with the neat and compact structures which go to make up metals. Thus at the outset we can expect a greater variation in plastics materials of the same genus as compared with metals, so that all possible control in the production of plastics is obviously essential. In the main plastics are carbon-based, so that these complex molecules will be vulnerable to heat, requiring therefore maximum consideration to be given during manufacture of the raw plastic and during the working of this into the end-product, in order that the ravages of heat treatment are reduced to the minimum.

Now we know that in some of the plastics structures the long chains move freely over each other when heat is applied, and we call these the thermoplastic materials. On the other hand, there are the thermosetting plastics which, if heated to the required degree suffer chemical change which locks the chain structure quite rigid, and prevents relative movement during heating. At one time we thought this broad family distinction was fixed and clear; today we know, following the work of Charlesby, that even the so-called thermoplastics can be rigidified or cross-linked in their structure by the application of high energy radiations, such as gamma rays.

From these brief remarks I think it will be clear to you that in plastics we have at our disposal many ways in which we can influence the performance of the final products. Optimum functionality can be expected from products of the most regular structure, and this regularity can be influenced almost as much by the conditions of fabrication of the end-product as by the actual control of the initial chemical processes which go to form the long-chain polymer. For too many years this vital fact was insufficiently appreciated, and good plastics were ruined in fabrication simply because the moulder



Fig. 21.  
Qualitative relationship  
between quality and  
structure of plastics—Dr.  
Swallow's diagrammatic  
representation.



made life as easy for himself as possible by literally "turning on the heat".

For many years, indeed since Carleton Ellis coined the phrase in reference to the work of Carothers, chemists have found ways of "tailoring the long chemical molecules" to give products of specific utility. In actual fact it is only really in the last few years that we have been really successful in this direction, and have succeeded in building up molecules of a specified pattern to give products of known and predictable properties. Just what these possibilities are was outlined by Dr. Swallow in his Cantor Lectures to the Royal Society of Arts a few years ago, and I cannot do better than quote briefly from his Paper his description of the various ways in which molecules can be aggregated in plastics irrespective of their chemical constitution<sup>25</sup>; the states of aggregation described are illustrated in Fig. 20. "In A we have the random arrangements of chains of different lengths which can be regarded as continuously coiling and uncoiling in three dimensions, like eels in a tub. These chains are held together in their length by covalent chemical bonds and in the chains themselves by those forces which occur between simple organic molecules. When, however, the forces between the chains are stronger and the

chains themselves less flexible, then we approach the condition of the amorphous thermoplastic shown in B. We can also have the structure which is in effect one giant molecule as C, in which the chains are joined together by the same forces as hold the chains themselves. These are polymers of the Bakelite (p.f.) type. If, on the other hand, the geometry of the chains is such as to fit into a crystal lattice, then as in D, the chains can crystallise along portions of their length. Here we assume that one polymer molecule can extend from one crystallite through an amorphous or disorderly region to the next crystallite, so that crystalline and amorphous co-mingle in the structure. When some of these crystalline polymers are stretched, the crystallites are stretched in the direction of stress, giving structures of increased strength such as shown in E, which is exemplified in the manufacture of nylon fibres.

"There is yet a further structure, such as F, in which the chains are branched, and the branches may crystallise among themselves. Thus we can differentiate broadly between the polymers in which the chains are flexible with weak inter-chain forces and which are characteristically rubber-like, those with less flexible chains and higher intermolecular forces which are amorphous, and those in which the

regularity of the chains is such as to permit crystallisation to occur along their length. In addition, we recognise those in which the chains are united laterally and longitudinally by the same covalent forces in the cross-linked or thermoset structures. Finally, we have those in which the chains are branched, and which in certain cases can crystallise within themselves."

Dr. Swallow also illustrated graphically the qualitative relationship between structure and properties, and this diagram reproduced in Fig. 21 will make clear and expectable the differences we know to exist between many common plastics<sup>26</sup>. On the vertical axis the intermolecular forces and/or the molecular stiffness of the chains increase, whilst on the horizontal axis the molecular regularity progressively increases. In general, therefore, the softening point of a polymer will tend to increase as we proceed from the left-hand bottom to the right-hand top corner of the graph, and plastics may thus be classified as shown in three overlapping zones, which are characteristically the amorphous or glass-like, the crystalline or fibre-forming, and the rubber-like. Fibre-forming properties in the polymer are quite clearly more exacting and, therefore, more limitative.

Today the chemist is able not only to predict the properties of his chemical structures in these general terms; he knows precisely how his groupings will build up, and he aids his chemical thinking by the use of three-dimensional models which show at once whether or not in any particular chemical structure he can literally make both ends meet. If he can do this, then he knows that the chemical polymer he will produce will be stable and functional. How different are these methods from those of but a few years ago, where empirical trial was the only method to find out whether or not any particular process would yield a stable and usable polymer.

This precise three-dimensional chemical thinking is well illustrated by what has been facetiously referred to as the 'new tactics in polymers', which has followed the work of Ziegler in Germany and Natta in Italy. This has shown that it is possible to determine the ultimate pattern of a polymer by laying down what is virtually an inorganic template in the form of an inorganic catalyst on which the polymer is actually pre-fabricated, and from which the then unwanted catalyst is eliminated in the final stages of production. Such is the accuracy claimed by Natta for the process of heterogeneous stereospecific catalysis that he can control with accuracy the way in which side groupings are attached to the main chain of the polymer. If they are all on one side of the chain then the product is said to be isotactic, if they regularly alternate it is syndiotactic, and if the addition is completely irregular, then atactic products result. The processes which have evolved as a result of this work are by no means of academic interest, since they have made possible not only the production of polymers of improved properties, but have also made possible the large scale and controlled polymerisation of such abundant and cheap hydrocarbons as propylene, which have

hitherto resisted the chain forming processes of the chemist.

The chemical advances of the last five years have brought us within reasonable sight of the ambition of the pioneers—the controlled tailoring of the giant polymer molecules, and the operative word now is "controlled". Chemically speaking we have attained our goal, or reasonably so; it now remains to bring the final fabrication processes into equal line as regards precision and accuracy. Just as good food can be spoiled by a bad cook, most certainly an excellent polymer can be ruined if the processes of fabrication used in the manufacture of the end-product are inefficient. The end-user is interested in the quality of his end-product; it is of small consolation to him to know that his unsatisfactory products were in fact actually produced from polymers of excellent properties. This can well happen if the engineering processes of final fabrication do not take the same note of the delicacy and accuracy of the polymer structure which was the guiding principle of the chemist who produced the raw polymer. I do not wish to imply that this problem is peculiar to plastics; it is assuredly not unknown to the workers in metals and woods. But we must all agree, I am sure, that metals and woods can more readily tolerate deficiencies in the fabricating processes than can plastics, since their molecular architecture is more robust and their structure is less complicated. From this suggestion that plastics are structurally more delicate than conventional metals and woods, it must not be assumed that the points of difference between the new and old are all in favour of the latter; plastics most certainly "have their points". Just how significant some of these are I hope now to prove.

### 3.2. Designing in and for plastics

In applying plastics in general engineering service, and more particularly when such application is in the nature of replacement of conventional products, we are faced with the difficulty that there are many points of performance on which we are completely lacking in data. When potential users ask us hopefully will your plastics do this or that, we can frequently only say with honesty, we don't know. To users brought up on the tradition of metals and wood, where performance data have been collected for over a century of almost all conceivable conditions of use and misuse, such an answer is often unacceptable, and the potential user returns frustrated to his metals or woods. The position, however, is not always hopeless, and by careful analysis of the service conditions given, extrapolation of available data, the application of accelerated tests, and above all the application of logical common sense, it is usually possible to assess what plastics can offer. In the "bad old days" the attitude was not infrequently to say that plastics could do any job short of making cutting edges and surfaces to meet direct heating; how sadly some plastics failed in consequence is now history. These days of misapplication of plastics are fortunately gone to a very considerable extent, and this is due in

no small measure to the fact that the processes of fabrication of plastics (using the term here in its broadest sense to include the manufacture both of the raw plastics and finished plastics products) are more perfectly understood. It is true to say that today the industry designs as much in as for plastics. The result is not only products of considerably improved functionality, but also products of greater aesthetic appeal. Let us take brief stock of what modern plastics can offer the engineer today.

The outstanding attraction of plastics as compared with metals is no doubt their lightness, and although for this they sacrifice a considerable degree of strength, their specific strength (strength/mass ratio) is high, as is shown in Appendix Table I. In many instances, however, the strength, though lower than that of metals, is adequate for the envisaged use. Indeed, it is possibly fair to say that had plastics been first in the field, the great weight of metals and the fact that in many cases they offered strength which could not be capitalised, would have reacted against them in competition. It is inevitable that performance standards are assessed in favour of established usage. Plastics are in the main easy to fabricate by comparison with metals, a fact which stems from their carbon-based structure and consequent temperature sensitivity; it is for this reason that they are mass-production materials *par excellence*. This reacts, of course, in the opposite direction in limiting the applications of plastics where high temperatures come in question (see Appendix Table II). The only materials offering extended temperature range are the fluorene polymers, silicones and certain epoxides, but in what may be termed the middle bracket, there are a large number which are useful over the range of temperatures normally encountered on this planet. On the other hand, at the low and ultra-low end of the temperature scale, many plastics are considerably more happy than metals generally. Thus, whilst one must admit certain temperature limitations for plastics, the position in this particular is by no means so entirely favourable to metals as many engineers appear to take for granted.

Outstanding among the advantages of plastics is, of course, their relative inertness and consequent resistance to corrosion; they do not rot, corrode or rust, although some types of plastics have their own form of degradation if improperly used. It is for this reason that plastics co-function so admirably with metals, the metal giving load-bearing qualities, the plastics giving corrosion resistance. Plastics are also poor conductors of heat and electricity, so that they are (and indeed have always been) well sought after for insulation purposes, for thermal and electrical work. Plastics possess remarkable damping characteristics which enable them to damp out vibrations in a way which metals cannot do due to their essentially different molecular architecture.

Compared with conventional materials plastics offer unique colour possibilities, and they go even further in that certain plastics can be offered alternatively coloured or glass-clear. On the other hand, the colour stability of some plastics is in-

different to poor, but in many instances this can be effectively compensated and, generally speaking, it can be said that when good colour and colour stability is required, it can be given in one or other of the commercial plastics according to the conditions to be met in the end use. Again this point of selectivity among plastics must be emphasised, and it may be a question also of selectivity within a plastics family, and not just from family to family.

So much for the advantages plastics have to offer as compared with metals but, of course, there is the other side of the picture; plastics are not without their disadvantages. Many of these stem from the fact that plastics are complex chemicals and of no very fixed and ordered or guaranteed structure. It is not surprising that they lack the dimensional stability of metals and are subject to warping, twisting, shrinkage and creep during use or storage. They are also vulnerable to energy radiation, and some of them can be decomposed to a greater or lesser degree when exposed to heat, light or high energy radiations. Some plastics give trace of their chemical ancestry in that they have an odour, either of their own, or residual from the parent chemicals. Occasionally this is a serious disadvantage, but it is a curious psychological fact that users who have for decades been prepared to tolerate a fish-glue adhesive, for example, are completely nauseated by anything more pungent than alcohol. During the past 10 years of intensive research much has been done to rectify some of these inherent defects, but the one which manufacturers can do very little about is their cost; plastics are expensive materials. This is due to the fact that the basic chemicals are *per se* expensive, and even at increased bulk production there can be little hope that the current price can be substantially reduced. In many instances plastics are of necessity materials suited only to batchwise-production, and although the current tendency is always towards continuous and automatic working, there are many instances where this cannot be applied.

Now how can we sum up between these pros and cons, or much more important, how does the potential user do this? I think I can say that currently his attitude is much more reasonable than it was a few years ago, when plastics were still regarded as "pseudo" materials which you only used if you could not get supplies of what were conventional products. A few years ago it was usual for a potential user to ask of plastics all the properties he had valued in metals, plus all those additionally advantageous ones he had visualised in his wildest dreams; and after this he mostly specified that the price must be lower than current for conventional materials. Progressive users were more reasonable and their successful application of plastics in new and conventional lines has set the pattern. In those earlier days we heard much of the virtues of metals, so much so that one came to regard these as near perfect. Now that plastics have proved their worth one hears less of the wonders of competitive metals, but more of their faults. I can look back on a four-hour train ride from the North of England some



years ago when I listened almost the whole way to a discourse from an eminent engineer on brittle fracture in metals. I listened and was well content, since I saw that in the face of such a defect the case for plastics was by no means hopeless. That there is on the contrary very considerable hope is evidenced by the progressive use made of plastics in America, where, of course, they try something because and when it is new, rather than wait as here in England "till all the bugs are out of it".

Currently the climate of opinion among engineers is I think changing; they are now prepared to give plastics a fair deal. The wise among manufacturers of plastics had foreseen this and, anticipating the inevitable swing which must come when convention could hold out no longer, had laid their plans accordingly. They have accomplished this as I have already said, by designing in and for plastics, that is they have selected their chemical groupings and reactions to give a polymer of a particular structure, and this they have fabricated by methods which not only capitalised but actually enhanced these properties in the finished end-user product.

Let me explain in a little more detail what I mean by this. You have all used polythene end-products in one form or another, and whilst over the past few years we have come to admire this material for its remarkable versatility, we have found occasions when unaccountable troubles have been encountered. Some of these were found to be due to just such variations of structure as I have already referred to, in that not only was the molecular build-up irregular, but the chains were not uniformly straight — they were in actual fact considerably 'branched'. To obviate this came new methods and new products, and with Ziegler's heterogeneous stereo specific catalysis, came the production of truly straight chains and the advent of what is sometimes called "linear" polythene. The result is a more rigid and generally harder material which is also more thermally-resistant, and all this has been achieved by design control on the structure of the polythene itself. In much the same way as this purely structural change, the design of polymers has been changed by the introduction of chemical groupings to achieve changes in performance properties. In all of these the chemist does not just guess, he works his designs out on a space model to make sure that they fit quite accurately and that there are no stresses, strains or unbalance in the finished molecule. In this the approach of the plastics chemist today is completely different from that of the pioneer days, when at the best his attitude may be described as "cook-it-and-see". I have given but one example — there could be hundreds; in all, the chemist is aiming to achieve the most regular and ordered pattern to produce a desired end-product.

But precision and attention to structure does not end with the production of the plastics. It is of equal concern to the fabricator and, as I have already said, good plastics material, like good food, has often been ruined in the cooking. How this is done differs in the various fabrication processes, but in all the golden

rule is to safeguard the polymer from an overdose of its arch enemy, heat, whether applied or 'work' heat. For the rest the fabrication should be carried out in a way as to give the maximum uniformity of molecular and chain structure and freedom from "faulting" and stress spots. An example of this, before the War, was the production of tough "Fibestos" cellulose acetate sheet by extruding the dough and maintaining the sheet so produced under tension, both transverse and lateral. The more modern example is the remarkable improvement in strength which is achieved by orientation when hot melt extruded nylon is cold drawn. A homely example in injection moulding is the production of the ordinary hair comb. Originally it was customary to introduce the plastic into the mould in the centre of what may be termed the "shoulder"; half went to the left and half to the right. The result was a complete centre of weakness at this point of entry, which resulted in easy fracture. The remedy was to introduce the plastic at one end so that it flowed in a clean sweep right along the "shoulder", resulting in maximum strength at the point of greatest stress in the middle. These are but a few examples of what is being done in the line of designing the plastics, both material and processwise, but we must be careful not to press this argument of oriented molecular structure too far since there are occasions, such as the injection of thin-walled containers, where we avoid the truly ordered chains along the length of the container.

Experience has shown that it is equally necessary to design for plastics. Early attempts were made to reproduce in plastics the general form of metal prototypes, frequently with disastrous results. After many early failures and much study of the detail of what happens to the material dimensionally during the fabrication process (as I have already detailed under injection), a procedure has been evolved to meet the particular needs of specific plastics. The overall result has been not only an improved article of enhanced performance, but in many instances an article of improved aesthetic appeal. We have gone a long way since the early empirical days, but there is still much to learn. Such has been the progress of the past few years as to prove even to the most sceptical what can be done with plastics. As a result of the success to date we are finding manufacturers willing to use and sell plastics as such, and there is much less tendency to try to pass them off under an alias as imitation something-or-other. An interesting example of the extent to which this abstract thinking supported by mathematical calculation can be applied, as much by the fabricator as by the manufacturer of plastics, was shown by my colleague Mr. L. W. Turner, in a Paper given in London 27. (See Appendix No. 5 for special note.)

### 3.3. Plastics to specification — current trends

It is sometimes difficult to realise that it is only half-a-century since the first conception of structural materials from chemicals was put forward as a serious commercial idea. Having regard to the



enormous potentialities of synthetics which are opening up today, it is almost as difficult to realise that possibly the greatest difficulty which has been encountered in the meantime has been selling this conception to industry. Even today, and particularly in this country, there are those who feel that plastics are not quite to be trusted, but against this is the growing climate of opinion among those responsible for major structures, that plastics are capable of more onerous work than has been entrusted to them hitherto. This is due in no small measure to the fact that today plastics are largely specification materials, and this goes not only for the basic chemicals and raw plastics, but also for the end-user products.

This represents almost as much a change in psychology as in technology, since in most instances it presupposes collaboration between the sponsors of the materials and the industries responsible for the end-products. This has been of reciprocal advantage to all concerned. No more is it necessary for the end-user to take risks and chance his arm using materials which the polymer manufacturer is not sure about any way. By getting together with his end-user, the plastics producer knows beforehand precisely what performance is expected of his material, and he not infrequently agrees a performance specification which will represent reasonably what he hopes to attain and at the same time is not vastly in excess of what the end-user can use and must have.

Quite apart from effecting thus a compromise in quality control and performance, the collaboration between manufacturers of raw plastics and finished end-products has given both such a knowledge of the manufacturing problems of the other as must inevitably improve both materials and methods of fabricating them. It is possibly fair to say that nowhere as in plastics has there been such free and constructive collaboration with end-users, and in consequence in no other industry are the user specifications not only designed to give adequate quality control, but actually give guidance for the best methods of working the plastics into the finished end-products. A good example of this which can be cited is British Standard 1972:53 covering the manufacture of polythene pipes.

The success which has attended this collaboration between plastics and numerous end-product makers in this country is evidenced by the remarkable list of British Standard Specifications which have been established, many of them in the past 10 years; a list of these is collected for reference in Appendix Table 6. An interesting development in this general direction is the Toxicity Report published a few weeks ago by the British Plastics Federation. For many years users found difficulty in believing that plastics which are chemicals could reach their end-product stage without inheriting some of the characteristics of their chemical ancestry. To the non-chemist it is possibly difficult to realise that in the condensation polymerisation which takes place between phenol and formaldehyde, for example, both the chemicals lose their identity and, in their place

comes a single polymer which is perfectly stable and quite phenol-free. Nevertheless, there have been cases where added chemicals, such as the plasticisers added to p.v.c. to increase flexibility, have imparted aroma to end-products, and there is an equal chance that such products might be toxic. This is of considerable importance today when plastics are used in food preparation and so largely in the packaging of food stuffs. The new Toxicity Report lays down a code which, if followed by manufacturers of plastics, will ensure that end-users may have every confidence in the products they handle. It will be of material assistance both to plastic and the food industries, and must enhance the general prestige of plastics.

#### 4. THE FUTURE WITH PLASTICS

In the early days of the industry it was customary for reviewers to speculate on the future of plastics. Such has been the progress of these materials in the past decade that I feel it is more accurate to speculate on the future *with* plastics; it would indeed be exceedingly difficult to imagine any future for society as we know it without plastics.

##### 4.1. Energy and material equation in the modern world

The co-significance of materials and energy came in this country just over 200 years ago when a new source of energy, coal, coincided with a new material, iron, and heralded what history has recorded as the First Industrial Revolution. There are clear indications that history is now repeating itself, but this time on a gigantic and global scale. By comparison with the first this second industrial revolution, as it may well be, will affect every part of this now closely integrated world,

When Zeta was announced a few weeks ago, Sir John Cockcroft characterised this wonderful development as ensuring unlimited power for all time. Such a statement could give the TV viewer a cosy feeling, make him sit back in his chair and think that nevermore will he be worried that lack of solid fuel will give him an empty grate and a cold room. But does it give us really this feeling of security, is energy in fact the only key factor in the life of man and nations? I submit that it is not; to be fully serviceable energy (except in the form of atom bombs) can only be capitalised through the medium of materials, and materials, at any rate traditional materials, are nature bound. To equate this stepped-up energy with the necessary equivalent of materials, would be virtually impossible in traditional terms. Woods are limited by the trees of the forest and metals by the ores stored in nature's storehouse; both are limited in quantity, vast though these are. Synthetic polymers by contrast can be stepped up at will, since the raw materials are available somewhere, and plants can be multiplied, given the capital. I don't want to push this argument too far, of course, but this I can say with confidence, the multiplication of supplies would be much easier

with synthetics than with traditional materials and, once available in a raw state, plastics can be fabricated into usable end-products much more rapidly than can traditional materials.

I am not implying in this suggestion that as materials plastics are self-sufficient; on the contrary, I am suggesting that their role is likely to be quite largely one of collaboration with traditional materials. Quite definitely, in consequence of this expansion of plastics, traditional materials will be more and more in demand, since to metals, wood, and ceramic, rather than to plastics will fall the need to produce the chemical plant which will be used in turn to produce the increased quantities of chemicals and plastics. Likewise, traditional materials rather than plastics will go to build the atomic energy plants which will liberate the energy and harness the power to the service of man. If it is a question of opening up new sections of uninhabited land, or irrigating desert wastes, then plastics rather than metals will carry the bulk of the load. Whether in the process of time we shall be able to design polymers which are largely inorganic-based, which will more nearly simulate the properties of metals I cannot say; I rather think we shall ultimately succeed in this direction. For the foreseeable future I think the picture is likely to be that traditional materials will carry very literally the bulk loads of industry, but the extended applications of the new found "Zeta" energy may be carried by plastics either alone or in collaboration with metals.

#### 4.2. Statistical — the economic significance of plastics

From what has been said and, of course, as you will substantiate from your own individual experience, it is very clear that plastics extend into almost every industry, and indeed in many industries their role is of a key and indispensable nature. Whilst the actual production and fabrication of the plastics themselves does not constitute a large industry, and the overall world production of these materials is small compared with traditional industries such as iron, coal and agriculture, it is true to say that today many old and established industries could not carry on without the assistance of plastics. From the point of view of prestige of plastics, it is perhaps unfortunate that in the end-use many of them are not evident as such; they are to a very considerable extent anonymous materials. Every motor car, radio set, indeed almost every industrial machine today, carries its quota of plastics, so that in many industries plastics hold the key. This spread throughout all industry is very significant for plastics, since it means whenever any particular industry succeeds plastics succeeds likewise, but when any one industry falls on hard times the result is not necessarily crippling for plastics. In many of their industrial applications plastics are co-functional with traditional materials, a trend which is particularly evident at the present time, and is likely to increase more and more as the years go by.

At the present time America is by far the largest producer of plastics in the world, and the industry

there has already graduated to what is perhaps the acme of industrial perfection, the billion dollar status. Next in line in production importance comes Western Europe where, according to O.E.C.C. statistics, sales exceeded the million ton mark for the first time in 1955, 90% of this being accounted for by Western Germany, the United Kingdom, France and Italy. Since the War Western Germany has made amazing strides in the rehabilitation of its plastics industry and now comes second to America in world rating. Whilst paying every tribute to the progress thus made, we must remember that in the case of Germany it was rather the rehabilitation of an existing industry than the growth of a new one. We have little knowledge of what is happening in plastics in the Iron Curtain countries, and from such examples of products as I personally have seen, it would appear that the quality of plastics production in Russia, for example, is inferior to our own. Nevertheless from their technical literature it is evident that very considerable strides are being made. Very much the same applies to Japan, which has always had a considerable and progressive industry, and which in the days before the War was well to the fore in polymer production. One surprising point about the world production of plastics is that despite the fact that more and more new materials are being manufactured the world over, export figures for plastics recorded for all the major producing countries continue to rise.

Another important fact worthy of mention is that in spite of the many new plastics which have been developed in recent years, very few of the old ones of reputable quality have fallen into disuse. Some of the pioneers, such as celluloid and casein, are certainly declining, but in Britain, at any rate, these materials are certainly very much in demand, and for many specific purposes are likely to remain so. It would appear that as the number of plastics commercially available is increasing, industry and the using public have become more plastics-conscious, so that the overall demand has increased likewise. In assessing the value of plastics in a national economy, we must remember that the production of these materials has stimulated industries which lie both before and after them in the production line. Thus the need for more chemical ingredients for the production of plastics has stimulated the development of the vast oil cracking industries, and in particular those producing what are today usually known as petroleum chemicals or 'petrochemicals', and likewise the availability of plastics co-functioning with conventional materials, and adding thereto their quota of improved properties, has been responsible for the developments in the electrical industry, such as radio, telephone, wireless, radar and many others. Without plastics many of these industries could not exist. In assessing the future of plastics production in any country we must always remember, however, that they are by nature 'footloose' industries and that exports of plastics from Britain and America, for example, have built up considerable fabricating industries in remote parts of the world, such as Australia and South America. It is quite logical and

natural that once such fabrication has been established and the end-user products find extending markets, the tendency will be to produce the raw plastics within the country of the end-use. This is a difficulty and danger which is at the present time facing the countries which have been traditionally responsible for the production of plastics, and the losses which inevitably must come in this direction can only be made good by extending the use of plastics in completely new fields.

For many years we have been considerably handicapped in assessing the progress of plastics, particularly in this country, by the lack of reliable statistical data; for many years statistics of production were confined almost entirely to those published in America by the U.S. Tariff Commission. This was very fortunate from the British point of view, since for many years the total absence of British statistics gave the impression abroad that progress in this country was either very limited or non-existent, and from the point of view of our own industry it was in consequence often erroneously assumed that the pattern of the development here followed that which was revealed by American statistics. Today the position is fortunately a very different one, and we now have available to us statistics of production of plastics in all the major countries of the world, and although in many instances these have to be accepted with some reserve and interpreted with caution, they do give a picture of world development. The availability of these production statistics, as with the availability of extended and reliable performance data, has in many instances given new and potential users added confidence in plastics. The knowledge of what a country is using or can use in the way of plastics materials, has also been of considerable assistance in defining export policy. Such statistics show that in many instances plastics have removed the traditional barrier between the 'have' and 'have not' nations. Some idea of the growth of plastic production in the three main producing countries is given in Appendix Table 7.

A very able and well-informed editorial summary of the current production position of the plastics industry in Britain has just been published in *British Plastics* 28. Overall production is expected to exceed the 400,000 tons projected last year, and of this total the thermoplastics account for the larger proportion, and the difference between the two sides of the industry continues to favour thermoplastics. Looking first at the thermosetting side, phenolic moulding material was among the few which showed little change during the year at 25,000-26,000 tons, against the currently rated capacity of the industry of 45,000 tons. Aminoplastic resins by contrast at about the same tonnage showed a 20% increase on last year. Polyester resins showed progress with a 50% increase on 1956 at around 3,000 tons. In the thermoplastic class pride of place still goes to the vinyl group, which at 68,000 tons was 30% up on 1956, and it is estimated that the current capacity of this branch of the industry is little more than 10% above the 80,000 tons production rate attained

at the end of last year. Among the major uses of p.v.c. a fall has been recorded in the off-take for coal mine conveyor belts, which is attributed not so much to a fall in demand as to the fact that thinner coating layers of the plastic are now applied to the fabric core. Next in production order comes polythene, which at 55,000 tons shows a 40% advance for the year, and the current trend is still upwards for both production and use. The third member of the poly trio, polystyrene, has shown a substantial increase (of the order of 25%) to 29,000 tons, which is most pleasing in view of the apparent lack of progress in this material for the past four or five years. Part of the reason for this increase is the bigger demand for high-impact grades for the manufacture of refrigerators, thin-walled containers and expanded insulating material, in all of which further growth can be expected.

A notable increase in the demand for acrylic sheet and moulding-powder was also recorded, the latter accounting for an increase in the I.C.I. output of the order of 3,000-4,000 tons a year. Nylon extrusion and moulding compounds, although by comparison relatively small at approximately 1,000 tons per annum, showed good progress in 1957. But it is perhaps surprising, having regard to the remarkable properties of these materials, that their main off-take is for the manufacture of combs. Sales of p.t.f.e. are also small, but are increasing satisfactorily, so much so that it is suggested that the increased production capacity of nominally 200 tons per annum at the I.C.I. Hillhouse plant may be taken up this year. This is a satisfactory position, having regard to the fact that the estimated world production of fluorine polymers is around 2,000 tons, mainly p.t.f.e. Some idea of the significance of plastics exports in the economy of Britain will be obtained from the statistics collected for the years 1950 to 1957 which are given in Appendix Table 8.

#### 4.3. Summing up — 'Whither plastics?'

There was a time, not so many years ago, when 'Whither plastics?' was a favourite title for surveys, lectures and even books. Today the question is rarely asked, not so much because in the meantime anyone has produced an inspired answer, but because it is fairly safe to say we know where we are going. When the industry was insecure, when it was by no means clear that plastics as a family had any abiding function, it was necessary to boost morale by justifying the existence and prophesying the continuance of the new materials. Today, as I have said, plastics are so entwined with the vital structure of industry that their future is assured so long as industry endures. Today we are in the fortunate position of the TV comedian who used to say with a superior air: "Don't bother to clap, I know I'm good". To some extent today in plastics we don't need boost of morale, we know we have the goods. But by this I do not imply that we are at all complacent — far from it. The current feeling of confidence is born rather of the knowledge that, for the first time in our history, we have such fuller knowledge of the materials and processes we operate as we believe will



lead us to attain that greater perfection which is now clearly possible. We have available to us a range of materials which together with conventional materials (and I stress this at all times) can meet the exacting needs of our age. We have within our grasp for the first time in history the potentiality to produce materials in almost unlimited supply, which will match the energy which atomic fission is making available to us.

What the pattern of the future is likely to be it is difficult to say. According to the fission experts it is likely to be 10-15 years before the energy of which Zeta has given promise is to be a realised fact. Against that day we could, at the rate of current progress, build up a production potential of synthetic materials as would go a long way to equate the material and energy needs of mankind at present standards.

To accomplish this on the material side we shall need considerable perfection of our knowledge of the mechanism and kinetics of polymerisation which, at the present time though promising, is little better than fragmentary. I do not suggest that the next decade will show any vast increase in the number of commercial polymers available; rather can we anticipate that we shall effect an all-round improvement in the quality of individual plastics. This we shall obtain by the use of improved raw materials and improved techniques.

I venture to prophesy that it is on the fabrication side that the major strides will be made, and here I view fabrication in its broadest sense — fabrication of raw plastics and end-products therefrom. To date the initiative has been with the chemist, but I feel that now the chemical engineer and the mechanical engineer will come into power and dominate the polymer field. With them even more than with the chemist lies the potentiality to improve the quality of future plastics. It cannot be too often stressed that the quality of the end-products lies in the ability to fabricate these with an upgrading rather than a downgrading of the delicate structure of plastics of which today, chemist and engineer alike, we are so conscious. This can be done by process perfection which will bring even more under control that arch enemy of plastics — heat. This may be attained by increased automation, and the development whenever possible of continuously operating processes.

If we look back we find that many plastics attained initial favour because of their allegedly easy working; glassfibre laminates were a case in point. Experience in this industry has shown that industry here started from an entirely false promise, with the result that, as Mr. Collinson pointed out in his recent Horner's Plastics Lecture, the glassfibre

laminated industry has virtually to start at the beginning again — this time on a mechanised and as far as possible automatic basis. Such is the variability possible in the structural make-up of plastics as compared with metals, that the processes of fabrication must be such as at any rate not to add to those variables. As I have already said, so many plastics in the past have, like food, been ruined in the cooking; clearly in the future all attention will be turned on the perfection of these 'cooking' processes from the raw chemical up to the finished end-products.

In Britain we have a goodly heritage in this new field of polymer production. Though not over-blessed with raw materials in the widest sense, our ability in the field of chemical synthesis will enable us to make the best use of those we have or can acquire. We have a chemical industry second to none in the world, and we can count many notable discoveries in the polymer field to our credit. On the engineering side we have a tradition for inventiveness and sound construction which again is second to none, and I am sure that our engineers will be equal to the challenge of the new materials, and will both produce them in high quality and apply them to good purpose. Many of us who have grown up with plastics have had cause to deplore the fact that we are an industry without a past. I suggest that this is of little consequence and that we should now console ourselves that at any rate we are an industry with a future — a great future.

As the pattern of our technological world is developing it appears that scientists are dividing broadly into two groups — those who take atoms apart and those who put atoms together. United they can give us energy for all time, together with materials far beyond nature's resources. Such a union could lead mankind to a world, if not of plenty, at least of adequacy for all. Let us above all hope that our collective efforts which at present have such great promise may indeed be used to enrich the world, and not to destroy it.

#### Acknowledgments

I should like to express my very sincere thanks to the firms who have so kindly and readily supplied me with illustrations of plant and have in fact given me more data than I have been able to use in this brief survey. I am also greatly indebted to my colleagues in my research laboratories who have assisted me with the preparation of details of various fabricating processes and in particular to Messrs. Flavell, Goodchild, Ives, and Turner; also to Mr. Shelton, who prepared the diagrams and flow sheets.

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## APPENDICES

Appendix Table I  
SPECIFIC STRENGTH OF STRUCTURAL MATERIALS  
(Tensile strength per unit weight)

Material	Tensile Strength, p.s.i.	Density		Specific Strength	
		g./c.c.	lb. ft. <sup>3</sup>	in.	ft.
Aluminium ... ..	30-40,000	2.7	168.5	360,000	30,000
Brass ... ..	50-150,000	8.7	543.1	159,000	13,000
Steel ... ..	40-330,000	7.8	488	140,000	12,000
Copper ... ..	60-70,000	7.3	455.1	200,000	17,000
Zinc ... ..	22-30,000	7.2	448.9	100,000	8,000
Tin ... ..	4-5,000	7.3	445.1	17,000	1,000
Lead ... ..	2,600-3,300	11	687	7,500	600
Urea-formaldehyde ... ..	6-13,000	1.5	94	184,000	15,000
Melamine formaldehyde ... ..	7,500-13,000	1.5	94	184,000	15,000
Phenol formaldehyde (G.P.) ... ..	6,500-8,500	1.4	87	150,000	13,000
Phenol formaldehyde (asbestos filled) ... ..	8,000-10,000	1.8	112	140,000	12,000
Methyl methacrylate ... ..	6,000-10,000	1.2	75	184,000	15,000
Polystyrene ... ..	5,000-10,000	1.05	65	200,000	18,000
Cellulose acetate ... ..	3,000-6,000	1.3	82	85,000	7,000
Nylon (drawn) ... ..	100,000				
Natural silk (raw) ... ..	64,000				

"Plastics in the Service of Man"—Penguin Books, London, 1956, 297.

**Appendix Table 2**  
**STRENGTH OF PLASTICS MATERIALS AND METALS**  
 (The order of comparative strength of plastics, metals and ceramics will be seen from the following table.)

Material	Specific Gravity	Tensile Strength, lb./sq. in.	Modulus of Elasticity, lb./sq. in.
Wood ... ..	0.63	16,000	$18 \times 10^5$
Plywood ... ..	0.68	9,600	$20 \times 10^5$
Polystyrene ... ..	1.06	7,000	$4.5 \times 10^5$
Polyamide... ..	1.14	50,000	$4.5 \times 10^5$
Methyl methacrylate ... ..	1.18	5,000	$5 \times 10^5$
Cellulose acetate butyrate ... ..	1.28	5,000	$2.7 \times 10^5$
Hard rubber ... ..	1.30	7,000	$3 \times 10^5$
Cellulose acetate... ..	1.32	6,700	$2.7 \times 10^5$
Phenolic plastic ... ..	1.38	7,500	$12.5 \times 10^5$
Lignin fibre ... ..	1.45	9,500	$17.5 \times 10^5$
Concrete ... ..	2.31	200	$2 \times 10^6$
Glass ... ..	2.60	9,500	$9 \times 10^6$
Aluminium ... ..	2.70	22,000	$10 \times 10^6$
Duralumin ... ..	2.79	55,000	$10 \times 10^6$
Aluminium die cast ... ..	2.90	29,000	$10 \times 10^6$
Zinc die cast ... ..	6.60	35,000	$13 \times 10^6$
Zinc ... ..	7.14	17,500	$12 \times 10^6$
Alloy steel ... ..	7.80	189,000	$30 \times 10^6$
Structural steel ... ..	7.85	85,000	$30 \times 10^6$
Nickel silver ... ..	8.68	108,500	$20 \times 10^6$
K monel ... ..	8.80	185,000	$26 \times 10^6$
Phosphor bronze ... ..	8.81	120,000	$15 \times 10^6$
Copper ... ..	8.89	47,000	$16 \times 10^6$
Lead ... ..	11.34	2,700	$2.5 \times 10^6$

Modern Plastics, 1942, 19, (6), 56.

**Appendix Table 3**  
**WEIGHT AND DENSITY OF PLASTICS MATERIALS AND METALS**

How plastics materials compare in density with the long-tried metals, woods and ceramics which are the conventional materials of construction will be seen from some of the outstanding plastics in the following table.

Material	Weight lb./cu. ft.
Wood ... ..	35
Polystyrene ... ..	66
Ethyl cellulose ... ..	71
Nylon ... ..	71
Polymethyl methacrylate ... ..	73
Cellulose acetate butyrate ... ..	75
Cast phenolic ... ..	81
Cellulose acetate ... ..	82
Vinyl resins ... ..	84
High-impact phenolic ... ..	86
General-purpose phenolic ... ..	89
Cellulose nitrate ... ..	92
Urea ... ..	92
Melamine ... ..	93
Saran ... ..	103
Heat-resistant phenolic ... ..	112
Brick ... ..	112
Magnesium alloys ... ..	112
Window glass ... ..	161
Plate glass ... ..	161
Aluminium alloys ... ..	175
Cement ... ..	180
Zinc ... ..	443
Cast iron ... ..	450
Tin ... ..	456
Steel ... ..	493
Brass ... ..	531
Bronze ... ..	550
Nickel ... ..	556
Copper ... ..	556
Lead ... ..	706

Weil, "Plastics Horizons," 133.

**Appendix Table 4**  
**IGNITION POINTS OF PLASTICS MATERIALS**

INSTANTANEOUS (less than 1 sec. contact)			MINIMUM (up to 10 sec. contact)
	deg.	Fahr.	
Cast phenolic .....	1600		
Mica-filled phenolic .....	1500		
Moulded urea .....			
Asbestos-filled phenolic .....	1400		
Polystyrene .....			
Wood-flour filled phenolic .....	1300		Moulded urea
Polymethyl methacrylate .....	1200		Mica-filled phenolic
Cellulose acetate butyrate .....			Asbestos-filled phenolic
Cellulose acetate .....	1100		Cast phenolic
Laminated phenolic paper base .....			Polystyrene
	1000		Wood-flour filled phenolic
Polyvinyl chloride acetate .....	900		Cellulose acetate
	800		Polymethyl methacrylate
			Laminated phenolic paper base
Cellulose nitrate .....	700		Cellulose acetate butyrate
	600		
	500		Polyvinyl chloride acetate
			Cellulose nitrate

Modern Plastics, 1943, 20, (6), 122.

## Appendix 5

### Calculation of processing requirements

Evidence is being collected regarding the flow behaviour of plastics materials in the molten state. For polystyrene, for example, it has been shown that, over a limited range of pressure (which is sufficiently wide to include normal injection moulding practice), a power-law can be employed to represent the relationship between shear rate and applied shear stress. In measurable quantities the rate of flow of material through a capillary will depend on the applied pressure raised to a power or  $Q \propto P^n$

The fundamental equation can be applied to the rate of extrusion from extrusion dies, or to the rate at which injection dies can be filled. This latter point is of special importance when thin-sectioned articles are to be moulded, since the filling-time is then a most critical factor. If, from a knowledge of material behaviour in respect of orientation, a desirable filling-time can be fixed, the developed equations can be employed to discover the injection pressure, that will be necessary.

For example, the equation

$$Q = \frac{f_0 \pi D L^{n+2} P^n}{2^{n+1} (n+2) L^n t}$$

applies to the case of moulding a thin cylindrical shape of length  $L$ , diameter  $D$ , wall thickness  $L$  where  $f_0$  is the standardised fluidity,  $t$  the filling-time and  $n$  the 'power' exponent. Thus, choosing a reasonable value for  $f_0$ , to mould a cylinder 6 in. long, 4 in. diameter and 30/1000 in. thick in section at a filling rate of 0.23 seconds, would require that a pressure of 3,500 lb. per sq. in. should be available at the die entrance.

This type of approach to engineering aspects of plastics processing is certain to increase as the fundamental physical properties of the materials are more thoroughly understood.

(See Turner, L. W., Paper delivered 25th March, 1958, at Conference on Technology of Engineering Manufacture, at The Institution of Mechanical Engineers, London.)

### Appendix Table 6

#### Collected list of British Standard Specifications relating to the fabrication of plastics materials and end-products

- |               |   |               |  |
|---------------|---|---------------|--|
| B.S. 488:1948 | Moulded insulating materials for general electrical purposes.                   | B.S.1203:1954 | Synthetic resin adhesives for plywood (phenolic and aminoplastic).   |
| B.S. 668:1936 | Laminated synthetic resin bonded sheet (fabric base) for use as gear materials. | B.S.1204:1956 | Synthetic resin adhesives (phenolic and aminoplastic) for constructional work in wood.                                     |
| B.S. 771:1954 | Synthetic resin (phenolic) moulding materials.                                  | B.S.1226:1945 | Draining boards.   |
| B.S. 972:1941 | Synthetic-resin bonded fabric sheet for electrical and mechanical purposes.     | B.S.1231:1945 | P.V.C. cables and cords for switchboard panel wiring.  |
| B.S.1137:1949 | Synthetic-resin bonded-paper sheets for use at power frequencies.               | B.S.1253:1949 | Technical mouldings (plastics).  |
|               |   | B.S.1254:1945 | W.C. seats (plastics).   |
|               |   | B.S.1314:1946 | Synthetic-resin bonded-paper tubes, for use as electrical insulation, for power circuits.                                  |
|               |   | B.S.1322:1956 | Aminoplastic moulding materials.   |
|               |   | B.S.1323:1946 | Synthetic-resin bonded-paper sheet (thermosetting) for use in the building industry.                                       |
|               |   | B.S.1330:1946 | Interim report on suggested methods of testing finished mouldings (plastics).  |
|               |   | B.S.1348:1949 | Measuring cups and spoons for cookery and medicine.  |
|               |   | B.S.1493:1948 | Polystyrene moulding materials.  |
|               |   | B.S.1524:1955 | Cellulose acetate moulding material.   |
|               |   | B.S.1539:1949 | Moulded electrical insulating materials for use at high temperatures.  |
|               |   | B.S.1540:1949 | Moulded electrical insulating materials for use at radio frequencies.  |
|               |   | B.S.1557:1954 | Polythene-insulated cables sheathed with p.v.c. for electric power and lighting up to 250 volts.                           |
|               |   | B.S.1588:1949 | Thermal insulating materials suitable for use within the temperature range 200°F to 450°F.                                 |
|               |   | B.S.1589:1950 | Thermal insulating materials (plastic composition, flexible and loose-fill).   |
|               |   | B.S.1755:1951 | Glossary of terms used in the plastics industry.   |
|               |   | B.S.1763:1956 | Thin p.v.c. sheeting (flexible, unsupported).  |
|               |   | B.S.1774:1951 | Rainwear from polyvinyl chloride sheeting. Part I — Fabrication.   |
|               |   | B.S.1776:1951 | Fabrication of lightweight articles (other than rainwear) from polyvinyl chloride sheeting.                                |
|               |   | B.S.1885:1952 | Synthetic-resin bonded-paper insulating tubes (rectangular cross-section) for electrical power circuits up to 1,000 volts. |
|               |   | B.S.1951:1953 | Thermosetting synthetic-resin bonded-paper round tubes for use at radio frequencies.                                       |
|               |   | B.S.1972:1953 | Polythene tube for cold water services.  |
|               |   | B.S.1973:1953 | Polythene tube for general purposes, including chemical and food industry uses.  |
|               |   | B.S.2004:1955 | Polyvinyl chloride insulated cables and flexible cords for electric power and lighting.                                    |
|               |   | B.S.2026:1953 | Tolerances for mouldings in thermosetting materials.   |
|               |   | B.S.2038:1953 | Rolled sheet metal screw threads and associated threads in moulded plastics and die cast materials for general purposes.   |
|               |   | B.S.2076:1954 | Thermosetting synthetic-resin bonded-paper insulating sheets for use at radio frequencies.                                 |
|               |   | B.S.2456:1954 | Floats for ball valves (plastics) for cold water.  |
|               |   | B.S.2487:1954 | Acrylic resin denture base materials.  |
|               |   | B.S.2552:1955 | Polystyrene tiles for walls and ceilings.  |

B.S.2571:1955	Flexible polyvinyl chloride (p.v.c.) extrusion compounds.	B.S.2766:1956	Moulded plastics ash trays.
B.S.2572:1955	Phenolic laminated sheet.	B.S.2782:1956	Methods of testing plastics. Part I — Effect of temperature.
B.S.2581:1955	Plastics trays.	B.S.2782:1957	Methods of testing plastics. Part II — Electrical properties.
B.S.2601:1955	Coated fabric (leathercloth) for upholstered furniture (p.v.c. type).	B.S.2782:1957	Methods of testing materials. Part III — Mechanical properties.
B.S.2601:1955	Coated fabric (leathercloth) for upholstered furniture (N.C. type).	B.S.2880:1957	Methods of testing cellulose acetate flake.
B.S.2601:1955	Coated fabric (leathercloth) for upholstered furniture (L.O. type).	B.S.2906:1957	Aminoplastic mouldings.
B.S.2739:1956	Thick p.v.c. sheeting (flexible, unsupported).	B.S.2907:1957	Phenolic mouldings.
B.S.2746:1956	P.V.C. insulation and sheath of electric cables	B.S.2919:1957	Low density polythene rod.

**Appendix Table 7**  
**PLASTICS PRODUCTION IN U.S.A., W. GERMANY AND U.K. (in 1,000 tons)**

	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957*
U.S.A. ...	713	708	851	926	1,000	1,200	1,662	1,467	1,703	1,995
W. Germany ...	48	75	108	168	191	225	334	425	505	600
U.K. ...	120	100	135	160	150	185	274	329	344	390
*assessed										

**Appendix Table 8**  
**U.K. PLASTICS EXPORTS**

YEAR	TONS	VALUE, Million £
1950	35,156	9.12
1951	53,123	16.3
1952	42,274	13.61
1953	56,465	16
1954	68,300	20.53
1955	73,298	22.81
1956	84,823	26.13
1957	111,800	29.9



## Appendix 9

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- "Engineering Properties and Applications of Plastics." G. F. Kinney. *John Wiley & Sons.* 1957.
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# THE 1957 GEORGE BRAY MEMORIAL LECTURE

## REPORT AND DISCUSSION

THE 1957 George Bray Memorial Lecture was presented and discussed at a general meeting of The Institution of Production Engineers in the Chemistry Lecture Theatre 'A', University of Leeds, on Monday, 24th March, 1958, at 6.30 p.m. **Mr. J. E. Hill**, Vice-President of the Institution, was in the Chair.

The **Chairman**, welcoming the audience, said he felt sure they would have the opportunity of adding to their specialised knowledge. It gave him particular pleasure to take the Chair because of his long association with the Yorkshire Section of the Institution, now known as the Leeds Section, and also because of his friendship with the late Colonel Bray.

The Institution were indebted to the University authorities for the facilities they had made available and he thanked the Vice-Chancellor, Sir Charles Morris, and the staff for their work in this connection and for the close liaison they had maintained with the Institution on so many occasions in the past.

The George Bray Lecture was established by The Institution of Production Engineers in 1952, when the Directors of George Bray & Company Limited, of Leeds, made a generous donation to the Institution, so that the income could be used to perpetuate the memory of the late Colonel George Bray. The Company was inspired to make this gesture because of the outstanding services given to production engineering by Colonel Bray over many years and in particular to the Yorkshire Section of the Institution, of which he was at one time President.

Many of those present had known the late George Bray very well indeed. The Institution, and particularly the Yorkshire Section, remembered him as one of the band of early workers whose help and enthusiasm ensured the success of the Section, and they were indeed indebted to him.

The George Bray Lecture was presented at an annual national meeting at which a speaker of outstanding merit was invited to give a Paper on a subject not traditionally associated with production engineering. It was fortunate that the word "traditional" was used, as the lecturer would probably tell them.

This was the fifth Lecture in the series. The first was also given in Leeds University by Sir Harry Pilkington, of Pilkington Brothers, who spoke on the manufacture of plate glass. Lectures had also been given by Mr. Robert Douglas, Sir Gordon Russell and Mr. Stafford Beer.

It gave the Chairman great pleasure to introduce Dr. Yarsley. To go into detail regarding his qualifications for giving the Lecture would take more time than had been allowed, but he was a man of outstanding ability and achievement.

The Chairman himself always passed over educational qualifications for the simple reason that personally he had managed fairly well without any. Dr. Yarsley had experience in industry and that was one of the things that really mattered. He had continued for many years as an independent consultant, a consultant specialising in plastics, and he was now in charge of a large staff dealing with consultancy and sponsored research and development in polymers and related materials. The details of his distinguished career were published with the Lecture.

*(Dr. Yarsley then presented his Lecture, which appears on page 402-441.)*

**Professor J. B. Speakman** (Head of Department of Textile Industries in the University of Leeds) said that before commenting on the Paper he must refer to the Chairman's opening remarks on the subject of education. No doubt he agreed with the Negro gentleman who summed up a discussion on education in America by saying: "Yes, Sir, if you ain't got education, you sure do have to use your brains". He took it that the Chairman, like Dr. Yarsley, had indulged in that exercise.

The lecturer was an expert in his field and he had not left much latitude for cross-examination. Attention might, however, be drawn to Table 7 in order to make a purely general point. This showed plastics production in the United States of America, Western Germany and the United Kingdom. Some attention had been drawn in the Paper to this table, but the striking and also frightening thing was that in Western Germany, since 1948 up to 1957, there was a 12-fold increase in the production of plastics. The United States, while showing a smaller rate of rise, had something of the order of an increase of  $2\frac{1}{2}$  to 3 times. This country was left standing as regards the total quantity, even taking into account the difference in population.

The difference between the three countries was also stressed in the text of the Paper, because the source of revolutionary changes such as, for example, the continuous methods of producing the open-cell flexible p.v.c. and the development of the cocoon method of enclosing machines as a whole (aeroplanes and others), was in the United States. The electrostatic process was presumably not British either. Fluidised solid coating was not British. There seemed to be evidenced in the production and inventiveness of the United States and Germany a reflection on the lack of co-operation between the chemist and the engineer in Britain.

A lack of co-operation was hinted at in the Paper and to some extent excused. The truth was that this George Bray Lecture had the greatest importance in bringing the chemist and the engineer together. Would the Chairman or Dr. Yarsley say what other methods there might be of ensuring that the gulf between the chemist and the engineer was bridged?

Everyone had seen the invasion of plastics in the home: the polythene bucket was a commonplace. Plastics had invaded the laboratory and wider fields also. But no one could have the slightest doubt that many engineers were still reluctant to make use of the new products, despite their great merits.

There was another problem he had been pondering on, and he hoped a solution would be found for it. At the moment, too much use was being made of foreign patents and too little was being done to develop patents in the United Kingdom. The attitude of many firms seemed to be to let others do the work and to rely on taking out a licence to use the subsequent patent. This did not earn money for Britain; patents ought to be developed in this country, and revenue earned by encouraging others to take out licences. In the field of plastics this could only be achieved through co-operation between chemists and engineers.

Finally, Dr. Yarsley had pointed out in his Paper that a revolution was going on in the chemical field in the production of plastics at the present time, starting with the work of Ziegler in Germany and continuing with the work of Natta in Italy. Chemical firms throughout the world were now working on new types of catalyst which made it possible to transform the properties of the plastics, as Dr. Yarsley had said.

As normally produced, polystyrene, for example, had certain well-defined properties which permitted a particular group of uses. But polystyrene produced with the help of a Natta catalyst had totally different properties and uses. Engineers should not assume that the plastics of tomorrow would have the same properties as those of today, even if they carried the same name, because of these remarkable advances in stereospecific polymerisation.

A revolution was taking place in the chemical field, and engineers should be alert to take advantage of the emerging range of new plastics.

**Dr. Yarsley**, in reply, said he would like to comment on production statistics, with particular reference to the case of Western Germany. He stressed that as far as Western Germany was concerned, since 1948 they were thinking of the resurrection of an old industry and not the building of a new one. Sometimes when adverse comparisons were drawn between production in this country and in Western Germany, insufficient credit was given to Britain for having built up production out of virtually nothing, whereas the Germans had only to rebuild their factories, and resume their production tempo at its very considerable War-time volume.

Also, there was as yet no uniformity the world over as to what should be called plastics. The Germans still included all their cellulosic compounds such as nitrocellulose for lacquers, viscose, etc., and this accounted for their remarkably high production figure of 50,000 tons a year ago.

He had seen a Paper read at the general meeting of the Chemical Society of the German Democratic Republic held in Leipzig in October, 1956, where statistics were given to show that the world increment for the period 1951-1955 was of the order of 78% for East Germany, and for the Socialist countries the increment was 216%. What was not



A guest at the reception preceding the Lecture is greeted by Mr. G. I. Bray (right), Sales Director, Geo. Bray & Co. Ltd., and (centre) Mr. R. H. Williams Vaughan, a Director of the Company.

said was from what figure they had started, a very important point in talking about percentages.

How was the gap to be bridged? In his own small organisation, where there were chemists and engineers, it was his experience that the gap was more rapidly bridged when the engineers understood the chemists' "shorthand". It was to the advantage of the chemist that he had this shorthand. The chemist could reasonably reckon to be able to do by horse sense what the engineer had to learn to do, but because of the chemist's shorthand, horse sense was of small assistance to the engineer.

The engineers now knew more of the rudimentary principles on which polymer technology and polymer building was taking place. This helped very considerably. It was a very difficult problem and he would certainly endorse wholeheartedly what Professor Speakman had said. He would recommend that if engineers tried a plastics material 10 years ago and found it an utter failure, it was high time they tried the modern version. Polystyrene and other related materials, on quality alone apart from their structural differences, were today unimaginably ahead of their counterparts of a decade ago.

He entirely agreed with the remarks about using other people's patents. The fluidised solid process had two patents. One could work from patents under licence, but this considerably hampered rapid development. A good example of this was the case of the Eichengruen patents in 1925 to 1930 for injection moulding, which completely hindered the development of injection moulding in Britain because people were not very ready to put down new machines when they had to pay 3d. a lb. of plastic injected to the patentees for the right to use the injection moulding process. Only in 1936, when the patents became free, did engineers take the injection moulding process seriously and commence developing sizeable machines. This was a tragedy from the British point of view. Although this country had the inventiveness and the knowledge, it still bought processes. It must not be forgotten, however, that there had been notable instances when patent monopoly had worked to the advantage of the British plastics industry, as in the case of polythene and "Terylene".

**Mr. F. Cass** (Chairman of the Yorkshire Section of The Plastics Institute) said that Dr. Yarsley had given such comprehensive covering to the whole subject of the fabrication of plastics that, as an engineer, he almost hesitated to butt in at all and say anything.

Great stress had been placed on the thermoplastics which came so much before the general public in the way of

polythene and polyesters, glass fibres for motor car bodies, motor boats and so on; but probably the plastic which interested the engineer most was the old thermosetting phenol formaldehyde. Mr. Cass remembered quite well the old bucket and spade method of moulding and the results obtained. The moulding industry itself thought it had a material which would supersede steel and perform absolute wonders. Of course, it did not. It had to be used in conjunction with the other materials and when this was done there was no doubt that it played a very important part. Standard tests had now been developed in conjunction with the British Standards Institution, which provided a good guide to the engineer as to what he might expect both mechanically and electrically.

He did not know whether it was generally recognised that phenol formaldehyde mouldings played a large part in life generally, in making it easy for the housewife through the modern gadgets she used. It had played a large part too in developing electrical apparatus, etc.

It must be recognised that phenol formaldehyde mouldings had certain limitations. One was the surface creep or tracking which took place under certain conditions; another was the very slight movement that took place after moulding. These points were taken care of in various ways, some by other plastics such as urea formaldehyde, the melamines and the alkyls, but these were not the absolute cures. They must only be used instead of phenol formaldehyde under the guidance of experts. He wondered whether Dr. Yarsley could describe any work which had been carried out to improve the phenol formaldehydes in this respect. Much had been done, but perhaps Dr. Yarsley could give an assurance that in the near future these difficulties would be overcome.

Personally, Mr. Cass felt that some of the newer plastics were being pushed a little too fast, just as in the thermosetting field they were pushed too fast in the early days of the industry. In many cases, whilst the claims were not entirely false, they had been made before the fullest tests had been carried out, and he would welcome Dr. Yarsley's views on these points.

**Dr. Yarsley**, in reply, said Mr. Cass had put the 64,000 dollar question. He himself thought some of the newer materials were being pushed too fast. He had nothing against the glassfibre laminates — far from it; they had their function and would come into their own. But too much stress had in the past been placed on the advantages of the use of low or contact pressures in the production of laminates. Mr. Collinson had recently pointed out, in his Horner's Plastics Lecture, that the glassfibre laminate industry had virtually to start again at the beginning. He had stressed that in production economics the most important thing was to keep the rain off the workers; in other words, to provide factory space, so that if a process was simplified by using large numbers of cheap moulds, the overall advantage was questionable. A speaker from the Bristol Aircraft Company, at the British Plastics Convention last year, had said that the glassfibre laminate

industry had to forget the simplicity theory. These materials had gained a bad name because people with inadequate knowledge had produced products of extremely poor quality. Little progress would be made unless engineers said for themselves what glassfibre laminates would do for them, and set out anew to base their production on sound mass production methods.

As a cellulose chemist he was a bit out of his depth on Mr. Cass's earlier question. All he could say was that in his laboratory some work had been done on surface tracking and he would send Mr. Cass a copy of the Paper in which improvements were referred to. Improvements to the surface of phenolic laminates could improve their electrical tracking properties. He could offer no suggestions about creep, but no doubt there were better qualified people in the audience who could offer some suggestions.

**Professor D. C. Johnson** (*Head of the Department of Mechanical Engineering in the University of Leeds*) remarked that Dr. Yarsley's Paper contained descriptions of a rich store of new materials and new means of turning those materials to use. They were very different from the metallic materials with which the engineer was familiar. He had wondered, however, why it was that the engineer should be just a little worried about this, because after all the differences between plastics and metals were no greater than the differences between metals and the other substances with which the engineer had long been familiar — wood and stone. Yet he accepted wood and stone and never made mistakes by using stone as if it were wood or wood as if it were metal.

He had then realised that this had really come about because with these other traditional materials there had grown up a trade, a technique, an understanding of their use. Those trades had originally grown up quite separately. The carpenter learned how to use wood quite independently of the worker learning to use metal. It was only at a later stage that the two could be combined and used by the same man, the engineer. When plastics came into existence there was no established trade. It all happened rather suddenly and, indeed, it was that trade, which was now growing, to which Dr. Yarsley had devoted his time.

It opened up great possibilities and it meant that when the engineer was faced with a design problem and wanted to know what materials to use, he was anxious to know the relevant properties of any material he was considering. He knew the relevant properties of the old materials by heart. He knew stone could not be expected to take tension. He knew wood was stronger along the grain than across it. These things were very much ingrained in his nature. If he understood Dr. Yarsley aright, he was suggesting that in the future the idea that plastics were just one thing would go. The designer would have to have some idea of the properties of the different plastics. The fundamental differences would become ingrained in his nature and, therefore, he would know how to treat them.

Professor Johnson himself felt a little sceptical about this, because he had a feeling that Dr. Yarsley and his colleagues were going to invent new substances more quickly than the engineers were going to learn how to use them. This posed a problem. Supposing one started to make a sump for a motor car engine, what were the relevant properties of aluminium that made it so suitable? There were a lot and most of them were never thought of at all. They were taken as read. There was strength against impact from stones thrown up; against handling in the shop; and the property of not fracturing when stones were thrown up was not a simple one. Strength to withstand vibration and fatigue limits must be high enough, and furthermore stresses



Obviously enjoying the occasion are (from left) Mr. J. E. Hill, Vice-Chairman of Council; Mr. G. I. Bray; and Mr. J. L. Townend, Honorary Secretary, Leeds Section.



from the thermal cycle of the engine heating up and cooling down must not cause failure. But this was only the beginning. The material must stand having hot oil on it without being attacked. It must stand splashes of dirty water on the bottom without being attacked. It must have a coefficient of expansion which was not too different from the material to which it was bolted. It must have a Young's modulus sufficiently high to enable an oil-tight joint to be obtained at the joint. It must not shrink under the load of the tightening nuts, so that they become loose. It must have the right heat conductivity.

He did not suppose he had thought of everything, but these items in themselves raised the question whether if plastics were selected, the engineer would ever really know the right qualities of this vast number of new materials. If he could not, what kind of tests was he going to use, and what kind of tests were used today? Was there an equivalent of the engineer's Izod test or of ultimate stress? Did these things mean anything? Could they be translated or not? Was there anything which would enable the engineer to say: "Yes, that would be a possibility. We can look at it further"? The tests engineers used were not tests of the relevant properties. They were only tests of recognition. They were the kind of tests one employed in interviews when one wanted to recognise the kind of man who would do a particular kind of job correctly. That kind of test, of course, if one had applied it to Englishmen for some time, could be remarkable misleading if one applied it to Chinese. Plastics might be a little like Chinese. Could Dr. Yarsley suggest any alternative test? Were there any?

**Dr. Yarsley**, in reply, thanked Professor Johnson for this interesting food for thought. All he could say at this juncture was that it posed the problem in a new way.

He had been in the plastics industry for a long time, and in that industry they inevitably borrowed techniques and test methods from a good many traditional industries, some from the natural high polymer rubber and some from engineering. A lot of the tests had been modified and adapted, and he had tried to stress that point in his Paper—particularly showing that plastics were specification materials. A long range of specifications had now been drawn up. This had frequently been done by a combined effort of manufacturers, fabricators and users generally.

One of the difficulties at the present time was that knowledge of the problem was not of long date. As he had said some little time ago, the plastics industry had been criticised for the fact that it was without a past, but conversely it could be argued that it was an industry with a considerable future. But it was certainly very difficult when engineers asked how materials would function after say, 10 years. Many of these materials had not been available for 10 years, and extrapolated tests in the form of accelerated weathering and the like could not give the data which time alone could provide. Plastics were therefore at a considerable disadvantage, and in many instances he had seen problems settled at this stage by a compromise, the new materials being insinuated on to the old and co-functioning therewith. Gradually the new materials would show promise in a new line, and be pushed further along in this way.

On the point that it might be confusing that there were so many plastics materials, Dr. Yarsley thought it was Mr. Renfrew, of I.C.I. Plastics, in a Paper to the S.P.E. some years ago in America, who said that there were not likely to be these continued rushes of new chemical compounds, and that chemists had now to some extent exhausted the fairly obvious and reasonable arrangements that could be expected. Within every family, as within the families of steel, brass and other metals, there were slight variations of composition and quality which gave a new brand. But he did not think that in the near future there would be an avalanche of new chemical compounds that would inundate the poor engineer so that he would be bewildered. He might have to learn that materials under the same general designation, e.g., under the name of styrene or polythene, might be quite different today from a few years ago, and might differ still more in a few years time. He might have to learn that a Natta polystyrene had a softening point



With Dr. Yarsley (right) in this group at the reception are Professors Speakman, Johnson and Whewell, of the University of Leeds.

considerably different from the softening point attainable by the conventional methods.

He thought progress was being made in the direction of establishing tests to give engineers information which would satisfy them.

As to the vulnerability of materials, he did not think metals were entirely faultless. Much had been heard in recent years about fatigue in aircraft materials, and in this connection he personally had been heartened after listening to an engineer friend who had beguiled a long train journey with an explanation of brittle fracture in metals. This had made it evident that traditional materials with which plastics have to compete were in actual fact far from ideal, and to some extent it was time to say that the intensive study of the physical properties of plastics had focused increased attention on the traditional materials with which they had to compete. Today all materials, both traditional and new, metallic and non-metallic, might be regarded as one family from which the engineer must draw for his many and very different structures, and in his own interest he should know as much as possible about all of them.

**Dr. C. G. Addingley** (*British Belting & Asbestos Ltd.*) said that most of the points he wanted to make had been touched on, though perhaps from a different angle, by previous speakers.

He had been struck by Dr. Yarsley's remark that at one time plastics were described as the grave of lost hopes for engineers. He was inclined to think they were now often the point of last resort.

Engineers had a habit of asking for a plastic material which had some particular property which they desired and could not get elsewhere, and at the same time expecting all its other properties to fit in with an existing design which they were unwilling to modify.

In respect of measurement and standardisation of physical and mechanical properties, much progress had been made. As Dr. Yarsley had indicated, some 50 B.S. Specifications had already been issued. In general, however, the test methods used were those traditionally applied to metals. These might give misleading results. Steel up to its yield point could be regarded as a truly elastic material, but most plastics were visco-elastic, and showed pronounced creep tendencies. For example, tests had been reported ("Modern Plastics", vol. 27, page 93, 1950) on a Phenolic plastics material with a tensile strength of 7,500 p.s.i. tested by

normal methods. Creep measurements on the material showed that the maximum stress it could sustain over a five-year period was only 2,000 p.s.i.

An example of practical application of plastics where suitable physical test methods were needed was the case of reinforced plastics pipes. Kellam has examined their potentialities as conduit to carry underground high voltage electric cable and concluded that new methods of evaluation were needed ("Reinforced Plastics", vol. 2, page 16, October, 1957).

The main purpose of these remarks was to emphasise the need for the co-operation of physicists and engineers, both in devising test methods for plastics products and also in producing designs which were suited to the known advantages and limitations of plastics.

**Mr. Griffiths**, speaking as a fundamental engineer, asked in what branch of engineering was it expected to use plastics? Was it machine tool engineering, or shipbuilding, or locomotives, or cotton machinery and things of that sort? He thought not. Plastics did not enter into those fields of engineering. But they could enter engineering somewhere between, and the motor car offered a very useful field for plastics.

He was at present interested and concerned in motor car engineering, and an effort had been made to put to the plastics engineer the type of plastics material that was required. These various names were all very well, but what engineers wanted was something that enabled them physically to do certain things. The big problem in the motor car engineering world was that for every ton of finished motor car, there was 1 ton of waste material. This was caused by the basic shapes of the materials used; and it was obvious that something different was required if an inroad was to be made into the massive waste of material. Plastics had something to offer with what he, as an engineer, called "squirt forming". It offered the greatest scope, and it meant that there would be very little waste.

What was required? Something that was stable within certain ranges of temperature. In the motor car industry stability was required between  $-50^{\circ}\text{C}$  and  $+100^{\circ}\text{C}$ . If the chemist could enter into engineering round that point and give stability between  $-50^{\circ}\text{C}$  and  $+100^{\circ}\text{C}$ , there was no doubt that the motor car body, mono blocks, and so on could be considered.

**Dr. Yarsley**, in reply, said there was again a lot of food for thought in what Mr. Griffiths had said, but it would be a long time in his opinion before motor bodies were 'squirted', though he could see the possibility of making them in other ways. The mould and machine costs would be considerable. It was difficult enough to design a 6 lb. bin; what would it be with a unit of the shape of a motor car body, which was presumably what was in mind?

**Mr. Griffiths** then mentioning panels, **Dr. Yarsley** agreed that would be better. Such a unit would offer a more controlled flow of the plastics binder through the reinforcing mass which was essential to give the required degree of orientation to long chain plastics molecules. This was all right in some cases, and for simple shapes it might be possible to "squirt", but probably for the applications Mr. Griffiths suggested, the glassfibre reinforced materials would be nearer the requirements. The particular properties which plastics can offer result by reason of their peculiar molecular architecture compared with that of metals in which the molecules are packed neatly within the crystal lattice. Among the many attractive properties of plastics they had a high damping factor, which was particularly useful in motor car body manufacture. As far as he knew the great difficulty was price. He thought head liners had been produced for car bodies by means of the vacuum forming process, and liners had also been formed for the inside of the body of the car, but the price was so high that it was difficult to meet. The prices one was accustomed to encounter in metal were certainly far below those quoted for plastics. Although there had been an attempt in the old days to dodge the issue and make out that they were not so expensive and could be made less expensive as production volume increased, it had been

found that there were limits, and it had to be admitted that they were *a priori* expensive materials. It was difficult for plastics to compete in motor car manufacture on the stressed parts, but he did not think Mr. Griffiths had those in mind.

**Mr. Griffiths**, concluding his remarks, said he must press the point that the stuff of which the washing bowl was made would be perfectly satisfactory for boots, lids, outer wings and doors, if it would stand a temperature of  $-50^{\circ}\text{C}$  to  $+100^{\circ}\text{C}$ . This was the important point.

**Mr. Rodger** asked whether Dr. Yarsley could give the connection between the gate size outside area and the volume of anything being injection moulded in cellulose acetate. Was there a definite relationship?

**Dr. Yarsley** said that there was a relationship. He thought that was one of the points his colleague Mr. Turner was dealing with at the forthcoming Conference in London, organised by The Institution of Mechanical Engineers. He could not give the information here and now, but would send it to Mr. Rodger.

**Mr. J. L. Burbidge** said he would like to bring the discussion back to the question of co-operation between the chemist and the engineer. It seemed to him that the chemist was developing materials with special properties, and was then expecting the engineer to find applications for them in engineering. The engineer, on the other hand, was faced with material selection problems and was expecting the chemist to find special materials to fit them. It was most unlikely that they would be able to alter this state of affairs, and it seemed to him to be a problem for electronic data processing.

There ought to be a centre to which anyone who had material of which he knew the properties could send this information. The same centre should then be used by designers with material problems, to find out what material would best fit their purpose. Was anything being done along these lines in industry in Britain?

(In a written comment subsequent to the meeting, Mr. Burbidge said he had since been put in touch with a new company in Farnborough, who were tackling this "clearing house" problem in much the way he had suggested, but so far without the aid of electronic data processing.)

**Dr. Yarsley**, in reply, said he had not heard the use of a computer suggested for such a purpose before. His knowledge of what computers would do was limited, but the cost would probably be a deterrent initially, unless there was a big centre to which a lot of information could be fed and which served a number of industries. In the latter case, it might be economic.

**Mr. R. Rajan** (*British Motor Corporation*) suggested that the engineer must first evaluate the properties of his materials. To look at them on paper did not mean very much, because with new materials it was necessary to apply new laws.

Some experiments had been made with nylon gear wheels. The properties of steel had been examined, and they had been taken as a yardstick of the requisite properties if a material was to do its job. Nylon wheels would not satisfactorily meet these requirements. But if one went further into the matter and carried out tests, one found that nylon, which actually had a very much lower tensile strength, would more than withstand the stress requirements, and in addition would do the job better. On analysis, this was found to be because nylon was a resilient material and, therefore, had certain properties not found in a steel wheel. With a steel gear there was a line contact and single tooth loading. With a nylon gear there were up to three teeth in contact at any one time, due to deformation of the material. In addition, there was complete tooth contact, not just along the line. Therefore, one could use a material which on the face of it could not do the job one wanted it to do, and get away with a number of things. These new laws were true not only of plastics material but

of a lot of other materials which on the face of it would not do the job.

One reason why engineers used a certain material was that it was the only material they had had in the past. If these new materials were to be used, there must be a whole new evaluation. What did this mean? Mr. Griffiths had pointed out that for every ton of motor car put on the road, a ton of material was wasted. That ton in itself was not the end. There was the capital expenditure that had to be put on the shop floor in order to cut away that ton of material. It would do a lot to reduce overheads if capital expenditure could be cut out somewhere along the line, either at the beginning or towards the finished product. In the end, it would reduce the cost of the article.

Dr. Yarsley had said plastics were expensive materials; therefore, they could not be used very much in engineering. He himself begged to differ. Nylon at 7s. 6d. per lb. was competitive in a large number of cases with cast iron, purely on wastage of material. In addition, there was the fact that an article could be made by injection moulding which was completely finished, and did not require cutting operations, thread milling and so on.

Dr. Yarsley said that a very interesting point had been made. He did not think he had said that because plastics were expensive materials, they could not be used in engineering. He had merely sounded a warning that they were expensive materials. Engineers had used these materials. Gland packings were one of the outstanding examples. P.t.f.e. at £21/lb., when made into a gland packing, competed on performance and longer life with tin, lead and metal foils which were used conventionally, and in addition the machines in which they were incorporated did not have to be taken down so frequently. This far outweighed the initial cost. Nylon gear wheels had the advantage of being stress free, and offered advantages in surface friction and so on.

But it was difficult to get engineers to appreciate that for years they had been using things they did not want. Chipboard (particle board) was a case in point. When chipboard was tried against tree board and broke under the load of a 17-stone man, people said: "Look, it breaks". But they conveniently overlooked the fact that if tree board had been tried under the same conditions it would have broken too. Their argument and general approach was conditioned entirely by users' convention, and many users conveniently overlooked the fact that many traditional materials were used for applications in which many of their physical properties were not used to the full. To reject plastics material which had the necessary strength, for example, to meet a particular use, simply because *per se* it was less strong than the material traditionally used for that purpose, was manifestly unfair to plastics. Engineers should be prepared to take a completely new look at the materials offered to them, and use them new and old alike, on the basis of the performance they could offer for any specific purpose. Plastics laminates with less than half the strength of steel might nevertheless do quite satisfactorily many jobs in which steel was traditionally used.

Dr. Yarsley agreed with Mr. Rajan's subsequent suggestion that prices should be quoted in pence per c.c., not shillings per pound.

Mr. D. H. Turnbull (*T. S. Harrison & Sons Ltd.*), speaking as an engineer, suggested that as a result of the Lecture and discussion, summarised information should be made available for engineers in simple, non-chemical language on the different types of plastics, their properties, the variation of those properties, present and possible future applications and trends, the weaknesses found in these applications and, most important of all, their economics.

If this information were available, together with information as to where further specialised advice could be obtained, this would be a great help. Engineers realised there was much they did not know regarding this very young and flourishing industry.

Dr. Yarsley said some publications along these lines were available.

Economic conditions changed rapidly, and it was difficult to persuade manufacturing firms to give more than very wide and general price quotations. Such comparative price guidance could no doubt be obtained from the British Plastics Federation.

The Chairman invited Mr. G. I. Bray (*Sales Director of George Bray & Company*) to propose a vote of thanks.

Mr. Bray said he was particularly grateful for the opportunity of proposing a vote of thanks. Apart from his natural appreciation as a member of the audience, he had a special reason for wishing to pay tribute on this occasion, as representing his family, his co-directors and his colleagues in the firm, many of whom were present. They very much appreciated the great honour the Institution paid to the memory of his father in inviting such distinguished speakers to present Papers on these occasions.

He felt sure he was speaking on behalf of everyone present in saying how glad they were that Dr. Yarsley had accepted the Institution's invitation. The feature that stood out particularly in his own mind was Dr. Yarsley's courtesy in going to such considerable time and trouble — as it must have been — to prepare his preprint especially for their benefit.

He had referred to it as documentary, and this was self-expressive; but it was a great pleasure, and most refreshing, to be able to listen to someone of acknowledged eminence in a specialised field who had cultivated the gift of making his subject matter intelligible to those whose expertise might lie in different directions. Dr. Yarsley's undoubted success in this direction had added immeasurably to their interest and instruction.

Whilst it might be a little premature to announce a forthcoming marriage between plastics and the production engineer, at least they might perhaps announce the engagement that evening. The next period should be one of getting to know each other. He personally was in no doubt of the outcome.

There had been so many highlights not only in the lecture, but in the discussion, that he felt he could not touch on any of them to advantage. He would, therefore, like to finish by proposing the heartiest vote of thanks to Dr. Yarsley for a most stimulating and enjoyable evening.

*The vote of thanks was carried by acclamation.*

The Chairman said he would like to thank the audience, many of whom had come at least 50 miles, for their support. It was a great pleasure to see them.

*The proceedings then terminated.*

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#### JOURNAL BINDERS

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#### RESEARCH PUBLICATIONS

The Institution is advised by PERA that Dr. G. Schlesinger's book on "Accuracy in Machine Tools: How to Measure and Maintain It" is now out of print and cannot, therefore, be supplied. The following I.Prod.E. publication is, however, still obtainable from PERA at "Staveley Lodge", Melton Mowbray, Leicestershire.

"Practical Drilling Tests" by D. F. Galloway and I. S. Morton. Price 21s.



# Air Gauging — History and Future Developments

by C. J. TANNER

A Paper presented at the Compressed Air Conference, Cornwall, in April, 1958.

AS electronics are increasingly used as the "brains" of automatic machining, so air-operated gauges will be chosen as the "eyes", to assess and signal or send impulses, according to how the process is running.

Present-day standards of dimensional accuracy, so important to the life and functioning quality of the finished product, can only be obtained with the help of modern gauges. These gauges must nowadays be accurate to a hundredth of a thousandth of an inch, make high magnification size indications possible, be reliable in service, fast in operation and convenient in use.

The inflexibility of an automatic process, and the often over-close relationship between the machining accuracy required and that obtainable from the machine tool, as well as the rigours of workshop life, combine with other factors to single out air-gauging as the indispensable key in its sphere of application, to progress and evolution in production methods.

Air operated gauges are no new invention. The first exploratory gropings for them took place almost certainly towards the end of, or soon after, the First World War. But, perhaps since early inventors were mainly unsuccessfully occupied with solving what have now become parameters off the main field of air-gauging, a valid basic principle was not established until Marcel Mennesson did so, a decade later, in the form of a flowmeter for carburettor jets. Next, in April 1932, to a sitting of the French Academy of Science, Mennesson presented a Paper describing how his flowmeter could be adapted to measure linear dimensions.

Other applications for his revolutionary invention came thick and fast to his mind, and long before the outbreak of World War II, the biggest proportion of present-day gauging problems had already been solved by him and examples were in use, mainly in France and Germany. Mennesson, therefore, is the true father of air-gauging.

However, in terms of numbers in use and ancillary refinements, air-gauges began their most rapid development later still. From the late thirties onwards, particularly with the pressure of War production, the industrial world turned at last wholeheartedly to air-gauges. Ever since then the field has become wider and wider in terms of variety as well as numbers of applications; that is to say, the choice between different variants of the air-gauging principle has equally become wider. Today, the mists of the future of air-gauging unroll each day to show still more fertile fields ahead, with gauging progresses hand-in-hand with other factors in the forward march of industrialisation.

## the basic principles

The features and characteristics of any gauging installation should, for purposes of considering its qualities, be clearly allocated to one of four distinct headings:

1. the taking of the measurement;
2. the "reporting" of it;
3. the general mechanical features (presentation of the gauge to the part or *vice versa*) and convenience of reading;
4. the maintaining and servicing of the installation.

The first two aspects are those of basic importance:

- (a) the geometrical correctness of the method of part location and of "sensing" the required dimension, and
- (b) the accuracy, in service as well as in theory, of the method of amplifying and relaying the results of this "sensing" to the size indicator.

However, the present state of development of air-gauges, and practical considerations, often lead to the would-be user paying more attention to the latter two points than to the former. It is time to say that the latter aspects are of great importance *provided the former are assured and unaffected*: in fact, it is in the



refinement of characteristics ancillary to the gauge proper that most of the competition between various air-gauging systems lies today.

Because of the importance of the basic accuracy of any gauging system, this must be ensured prior to beginning any efforts to refine it. I will first examine, therefore, if at no great length, those considerations relevant to taking and reporting of the measurement required.

### 1. taking the measurement

This is, in the largest number of cases, an identical problem for all metrologists. It is a geometrical problem, of "holding the part" and locating and deciding the form of the measuring points. Thus, relevant considerations are basically the same, irrespective of the gauging system being used (i.e., however much an inadequate gauging system may fail to encompass the problem of faithfully reporting this act of measurement to its visual size indicator).

There are, however, many special cases where on this score air is strikingly at an advantage over other systems because of its very fluidity — for example, the measurement of cross-sectional areas such as jets, nozzles, yarns, wires, etc., on delicate surfaces and of dimensions based on axes which are not "fixed" during measurements.

### 2. 'reporting' the measurement

Here air is outstandingly attractive as a medium — so far no other system can compare with it on the huge majority of problems. In effect, the special inherent qualities of air-gauging are not all embodied in every air-gauging system — this is where differences in principle begin between air-gauging systems.

In general, however, the most striking feature of air on this, the other basic aspect of any gauging problem, is the possibility of obtaining magnification and reporting of the sensory (size-taking) device's finding, without mechanisms of any sort. This can avoid errors from such causes as hysteresis, back-lash, wear, vibrations, operator uncertainty, fragility, and other confidence destroying phenomena.

For many years it was thought that the major advantage of air-gauging was that non-contact

measurement can so often be provided. That it is sometimes an advantage (deformable or delicate parts) is certainly true, but it is now generally recognised that air-gauging retains its superiority in cases where contact measurement can be used. This is because the true quality of air-gauging is *the use of air to amplify and report*, and not (in general) because of its use in *taking the measurement*. The writer goes further, and maintains that non-contact measurement can, in fact be considered as only the secondary, however often compulsory, type of solution by air-gauging — to be used when the contact solution is inadequate, but not in preference to it normally. It is even possible that the earlier preoccupation with the special advantages of non-contact measurement and the incorrect insistence upon describing its importance as being basic in air-gauging, concealed from many for years the true worth of the air-gauging in relation to mechanical and other principles. The true situation is discussed a little more fully in what follows.

### basic solutions in air gauging

It may be remarked in passing that the simplicity in functioning and use of air-operated gauges in no way implies that the technical considerations involved in the choice of, and in then obtaining, the air flow characteristics required in each case, are anything like as simple as they seem. They are not. In practice, too, considerations born of the handling problem, and of the comparative convenience to the operator of various forms in which readings can be given as well as of the maintenance and servicing problems, can often further complicate the issue by affecting the validity of the original basic solutions to the two fundamental points discussed above (i.e., of the four headings as set out).

Methods of taking the measurement can be broadly classified under three headings:

#### 1. by restriction (Figs. 1 and 2)

Here air is fed through a jet which of itself partially obstructs free flow. Thus the degree of obstruction can be used, as will be explained later, to give a flow



Mr. Tanner served his apprenticeship in the Tool Room of The Sunbeam Motor Co. Ltd., Wolverhampton, and it is worth noting that in 1922 this firm was one of the few to have a Trade Apprenticeship School run by the management.

In 1931, Mr. Tanner was associated for a short period with H. M. Hobson Ltd., Wolverhampton, in their Experimental Department, and in 1934, he joined Messrs. G. H. Alexander, of Birmingham, in charge of Inspection and Planning of sub-contract jigs and tools at a new factory at Dudley. He remained there until 1939, when Messrs. Rolls-Royce established their new factory at Crewe, for the production of Merlin aero-engines, and Mr. Tanner took charge of the Standards Room.

In 1952, he joined his present Company, Solex (Gauges) Ltd., and was appointed General Manager in 1954.

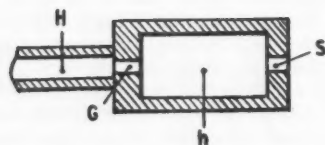


Fig. 1.

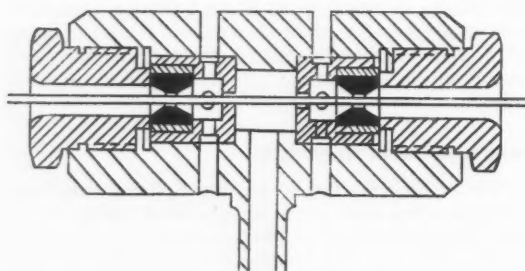


Fig. 2.

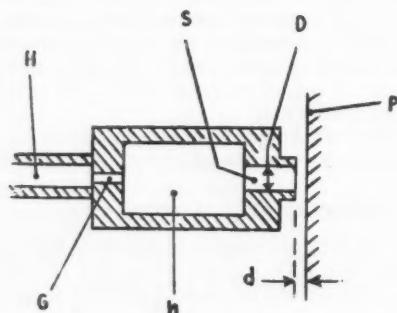


Fig. 3. Direct measurement by non-contact jet.

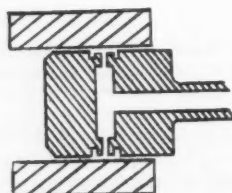


Fig. 4. Single diameter air plug.

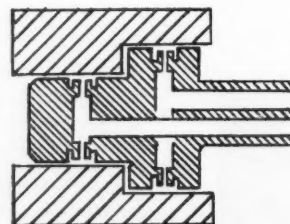


Fig. 5. Two-diameter (dual) air-plug.

value to that jet compared with a known master. This was the first application of air-gauging, now nearly thirty years old, checking carburettor jets.

Fig. 2 represents one of a number of other early applications on the same lines. In most practical cases each of such problems is special, difficult, and adds little to the fund of experience in the work which forms the main activities of a commercial gauging concern, and therefore none was energetically pursued when first brought out. The National Physical Laboratory has, as one example, however, since the War revived a number of such early solutions incorporating their own experimental control/indicating system to complete the installation. Typical, therefore, of these problems is that shown in Fig. 2, the obstruction of flow through a jet, by passing a wire or thread or other porous articles such as wool or, as has been done, cigarettes, into the jet.

## 2. by direct measurement

Here, for reasons easily understood, a mere orifice through which the flow of air is restricted by the orifice's proximity to a wall (of the part to be measured) is not enough to assure proper readings of comparative size against a master. A correct jet, with provision for free exhausting of the air after passing the measuring area, is used (Fig. 3). The measuring jet (S) is then fixed, and the flow of air through it varies because the jet is nearer to, or further from, the wall of the part to be measured. The flow can then only be influenced by variations in the distance (d) between the jet and the wall (P) of the part. In such cases, more than one measuring jet (S) may be used. If two are mounted in the skirt of a plug gauge at either end of a diameter, the insertion of the plug into a cylinder will allow measurement of the diameter of that cylinder by measuring the total flow through both jets.

It may be noted that it is over an area on the surface of the component, that the jet measures — an area represented by the annulus formed by the jet's inside diameter (D) and the equivalent area on the wall of the part opposite. The annulus formed by the jet land plays also a secondary but not negligible part in the measurement.

Figs. 4 to 8 show the same principle applied to a few of the many measurements which can be taken by two or more jets in circuit, and all of these become self-evidently possible as soon as Fig. 4 is examined; indeed, these and many others have been typical Mennesson solutions for many years. Freedom from the influence on the reading, of the position of the component being checked in relation to the gauging head, is the aim of many such arrangements. Restricted space and "linking" of several inter-related measuring points to give one reading (average diameter measurement for example), or delicate surfaced parts, are reasons for choosing this type of solution.

### 3. by indirect (contact) measurement

A number of variants of this method exist, but in one form or another the bulk of air-gauging problems are probably solved this way today. Fig. 9 shows a typical example — a poppet valve type, the tip of whose stem rests on the component. The "size" of this component at the point of measurement gives a certain degree of opening to the valve. Such "indirect" measuring heads are generally called "enclosed measuring jets". Subject to the same laws of air flow as direct measuring jets these units can likewise, where space permits, be "linked" to give measurement of special types of "dimensions", such as bore-to-face-squareness, straightness, etc. etc. They, too, can be designed to give special characteristics to the form in which the measurement is "reported" to the indicating instrument, to suit various user requirements.

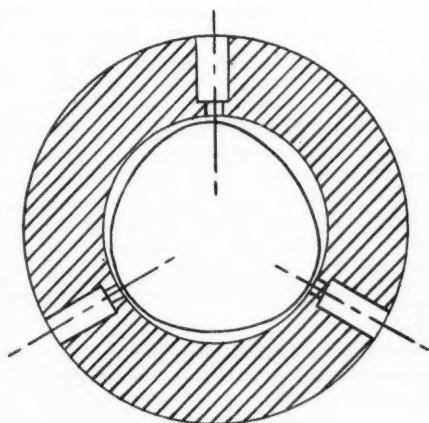


Fig. 6. Determination of lobing (three jets).

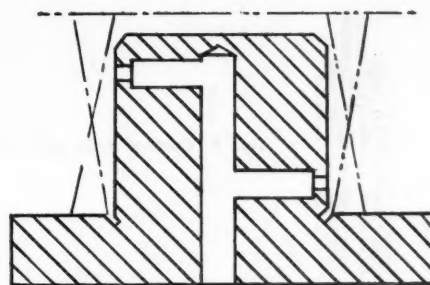


Fig. 8. Determination of squareness (bore to face).

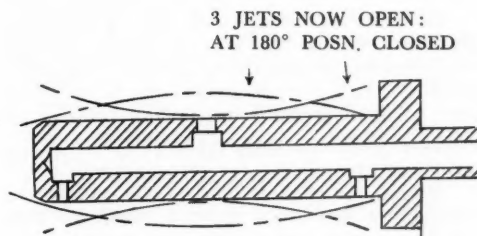


Fig. 7. Determination of bore alignment.

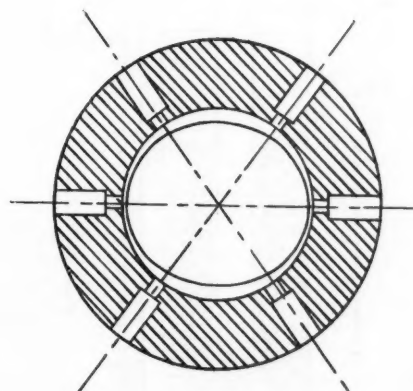


Fig. 6(a). Determination of average diameter or ovality (six jets).



There are a few specialised systems which do not,

Before passing to a consideration of some of the air control indicating systems available, it is appropriate to note that it has been frequently, but inaccurately, said that air gauges can be divided into what are then termed "back pressure" and "direct flow" classes (with "differential" systems forming a third type). The fact is that what is perhaps the best known of the so-called "direct flow" gauges is also itself a back pressure gauge—it uses the pressure difference caused by air flow through a vertical, tapered tube passing the restriction formed by a float or bobbin. It is a most successful method in very many respects, though it has its disadvantages. To put the matter in its correct light, the attempted distinction referred to is at best only an arbitrary one of degree, not one of principle. It is comparable to the difference between a voltmeter and an ammeter—they differ only by the arrangement of external resistors. This indefensible classification—direct flow or back pressure—would have no significance even if it were correct, since air gauges are based on the rate of flow of air and differ only in their methods of measuring this. It is hoped that the technical inaccuracy in existing literature which has dealt with "direct flow" and "back pressure" distinctions, has been made clear, the main point being the resultant difference in characteristics.

The SOLEX principle and the basic developments of it are made valid by meeting two conditions:

- 
- A schematic diagram of a vertical tube. A piston is at the top of the tube, with a force  $P$  applied to it from the left. The piston is connected to a horizontal rod that passes through a seal. The seal is labeled  $G$ . The rod is labeled  $H$ . The tube is partially filled with a liquid, indicated by a dashed line. The height of the liquid column is labeled  $h$ . The total height of the tube is labeled  $H$ . The tube is labeled  $V$ . The liquid is labeled  $R'$ . The tube is labeled  $T$ . The piston is labeled  $S$ . The seal is labeled  $G$ . The rod is labeled  $H$ . The height of the liquid column is labeled  $h$ . The total height of the tube is labeled  $H$ .

**Fig. 10. The SOLEX principle.**



consideration of atmospheric conditions at any time;

2. There must be no uncontrolled leakages of the air between the control jet ( $G$ ) or the measuring jet ( $S$ ).

These conditions are satisfied by the use of an air controller (Fig. 10) and proper connections between the air controller and the gauging head. Constant pressure is achieved by means of an hydraulic overflow. Air, from a compressor or factory air-line, is fed into the instrument — so long as the air line pressure ( $P$ ) is higher than ( $H$ ), which is the length that the open-ended dip tube ( $T$ ) is immersed in the reservoir ( $R$ ), air will escape by bubbling from the lower end of the dip tube.

Thus, so long as air is bubbling from here, the pressure of air in front of the control jet ( $G$ ) will be rigorously constant. Increase or decrease in air-line pressure will merely cause a greater or lesser degree of bubbling.

Having controlled the pressure of the air, the latter then passes through the control jet, which meters the amount at that pressure ( $H$ ), which can be delivered to the measuring jet ( $S$ ).

The manometer ( $M$ ) is placed between the control jet and measuring jet, and variations of flow through them cause the pressure ( $h$ ) to push the water column to a greater or lesser extent down the manometer tube. The only variations being those of the flow through the two jets, this simultaneous, balanced, flow in series through the orifice of known size ( $G$ ) and ( $S$ ), eliminates any influence of the ambient atmospheric conditions such as temperature, humidity, barometric pressure, etc. Thus, variations in flow can only be caused by variations of ( $S$ ) — that is to say, variations in the dimension to be measured.

The air controller is connected to the gauging head by means of an airtight flexible connection of suitable length.

The method of air-gauging described so far was the first to be developed commercially. Though based on exactly the same principle, many variations in the particular instruments used have been developed and quite a few have appeared on the market.

In one obvious method, used almost from the beginning and representative today of a number of makes, the precision hydraulic air regulator as described above is replaced by a commercial regulating valve and a standard Bourdon Pressure Gauge is used to indicate the readings against a calibrated scale.

In view of the normal available types of instrument, a constant pressure of 30 to 40 lb. is usable for this type of air gauge.

Most makers endeavour to improve on the standard commercial accuracy of both reducing valve and pressure dial gauge, in order that the pointer movements will not be affected by backlash of the gear mechanism (Fig. 11). Amongst other manufacturers, this type of equipment is produced by Messrs. Pratt & Whitney, and Federal and Mercer.

By using a differential manometer, i.e., a Null method, the effect on the readings of the instability

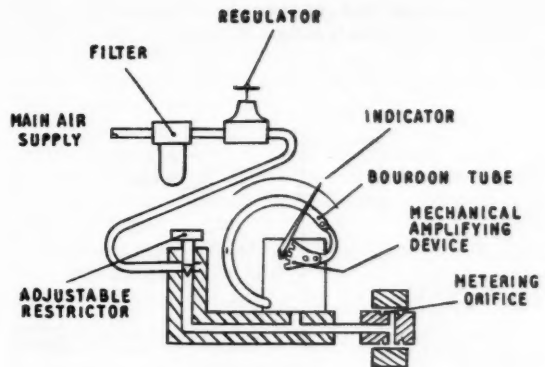


Fig. 11. Diagram of Bourdon tube air circuit.

of the reducing valve can be eliminated to a certain extent. In this type of air gauge, the intermediate chamber is duplicated and a reference nozzle, usually adjustable, is placed at the outlet of this second chamber instead of the measuring jets.

A differential manometer connected between the two chambers shows if the flow of air through the gauge is higher or lower than the flow through the reference, the reference jet being adjusted initially to balance a master component; any component which balances the reference is identical to the master independently of the constant pressure, and any difference in size will be shown on the indicator — but the reading is not dependent of the actual value of the constant pressure. This system is similar to one used by The Etamic Co. Ltd. (Fig. 12).

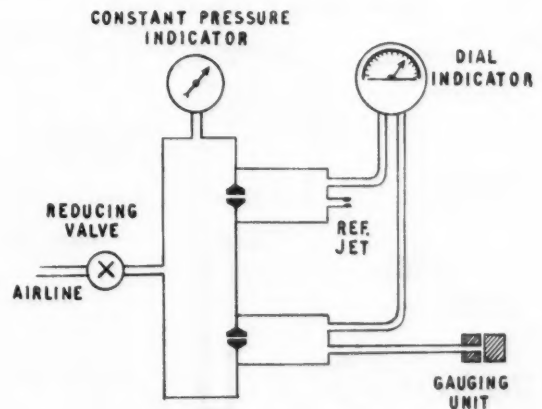


Fig. 12. Etamic principle.

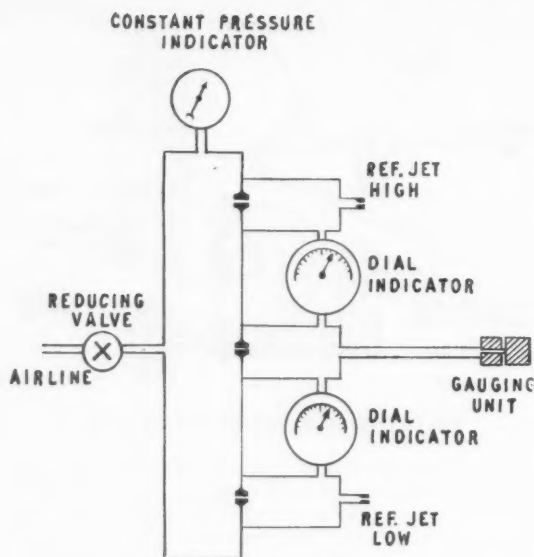


Fig. 12(a). Variant of Fig. 12.

In another variation of the differential air gauge, a lower pressure is used, between 2 to 10 lb. p.s.i., with an improved air regulator, and the water column is retained for sensitivity and reliability.

With this type of gauge it is, however, necessary to include some means of preventing the water flowing out of the manometer tube, when removing the gauge from a component, or inadvertently closing any reference orifice or measuring jets.

A classical way of solving this problem is by separating the manometer in two portions, by an extremely flexible membrane limited in movement. This system is used extensively by Messrs. Sigma in multi-gauging applications (Fig. 13).

In a more definite departure from the classical types of air gauging systems, the flow of air through the gauge is measured with a Rotameter type of

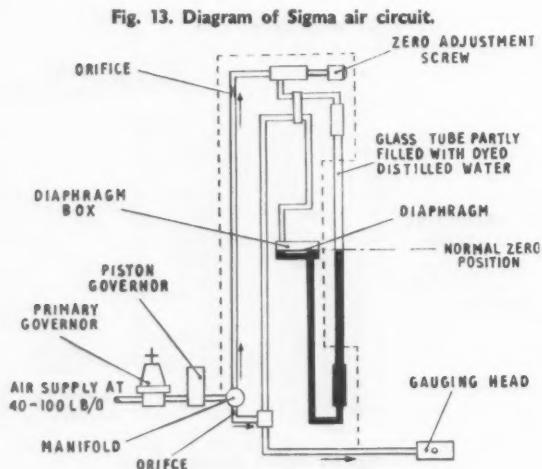


Fig. 13. Diagram of Sigma air circuit.

indicator working in a tapered glass tube. In this system, the difference of pressure is now constant, and it is the restricted orifice which is variable. A pressure to the order of 10 lb. is usual with this type of equipment, but a special type of reducing valve is necessary to ensure absolute accuracy. This system is used by Messrs. Sheffield of U.S.A. (Fig. 14).

Each type of instrument therefore has its own advantages and disadvantages. Some of these are important, some not. For example, the instrument shown in Fig. 10, designed some 30 years ago, numbered among its advantages, from the start, low pressure and the control jet system, and with its observance of Boyle's law, consequently obtains stability of individual scale calibrations under varying atmospheric conditions. No maxi-mini setting pieces are needed therefore—just one reference piece of any known size in or near the component tolerance. What is often considered of much greater importance is its comparatively low air consumption. It incorporates a liquid column manometer which has proved superior to alternative indication on the score of its ease of reading, always a virtue, but one which becomes striking in multi-column installations. It was in the past conversely criticised with debatable justification for slowness in giving a reading (usually the length of connector between gauging head and controller has been advanced as the explanation, which is technically incorrect) for the need for topping up the water reservoir at regular intervals, and for failing to "clean" the part as it measures it, in cases where a direct jet is used in the presence of an oil film. These were all criticisms, not on the vital first two of my four headings, but on the score of the third and fourth headings—convenience of use and maintenance. These problems were completely overcome in a developed version (Fig. 15) which incorporates other refinements as well, while remaining exactly on the original sound basic principles.

The instruments shown in Figs. 11 to 14 and others also have their advantages and disadvantages, and one can remind all concerned that what may be valid criticism today may be out of date tomorrow, as fresh developments and improvements come along. Air gauging is a live and rapidly growing branch of industry.

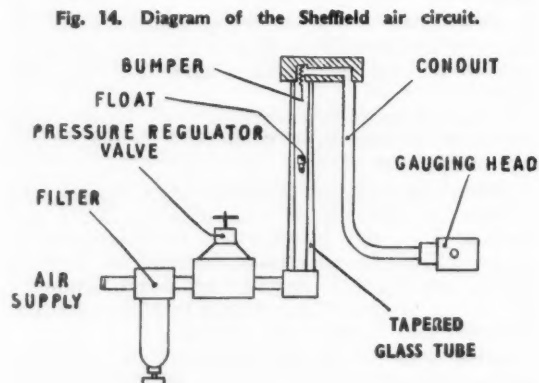


Fig. 14. Diagram of the Sheffield air circuit.

### some present day applications

Practically every application, from a pure gauging point of view, can trace its ancestry back 15 years or more on the air gauging side, and further still on the pure geometrical side. Thus the large part of the interest of all these modern applications lies, as I said early in this Paper, in the refinements incorporated to improve handling of gauge to part or *vice versa*, or to improve the way in which the reading is given, and also to make such gauges easier and more satisfactory to service and maintain. Hydraulic or pneumatic insertion and extraction of components or gauges, gauging stations built into conveyor lines, gauges fitted on to machine tools, gauges built into machine tools, gauges signalling defects or information to an operator, setter or electronic brain, gauges used for tool-setting or slide adjustment, gauges which work more reliably than before with the minimum of attention, gauges which are "fixed" to check a given dimension only, gauges which are adjustable for use on many different components — none is altogether new, all are gradually improving and becoming easier to use.

Application techniques become easier to understand and to develop if a proper definition of the

main categories of use is attempted. This is particularly so in times of rapid change and progress, when new words like "Cybernetics" are flying from mouth to mouth and not always ending up with the same meaning with which they started.

The following, therefore, is an attempt to define only some of the newer of these expressions, and the gauging installations shown and described in Fig. 16 to Fig. 29 are designed to illustrate examples in practical use.

**Production gauge:** used by the machine operator or setter to assist in machining the component to the required size by measuring the part during or after the machining operation. (Fig. 16)

**Setting adjustment gauges:** gauges used by the machine operator or setter to translate the findings of the production gauge into accurate manipulation or setting of the machine or tool. (Fig. 17)

**Production (or inspection) gauges:** which check dimensions outside the machine operator's control, but usually *within* the setter's control.

**Line inspection gauges:** often incorporating both setting checks and production checks, whether or not the indications of such gauges are directly used to manipulate the machine tool. (Figs. 21—29).

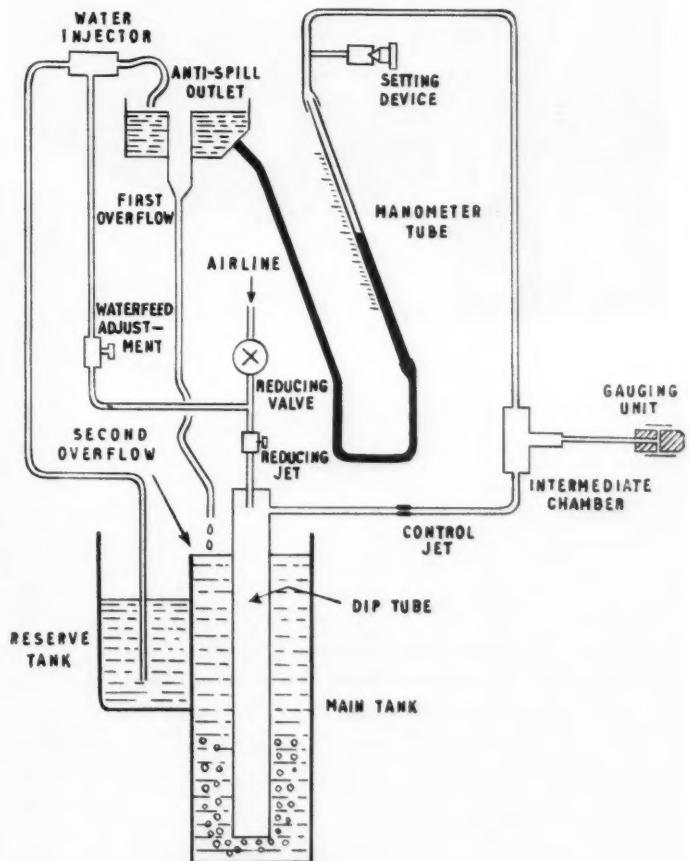


Fig. 15. Diagram of general air controller circuit showing one gauging section only.

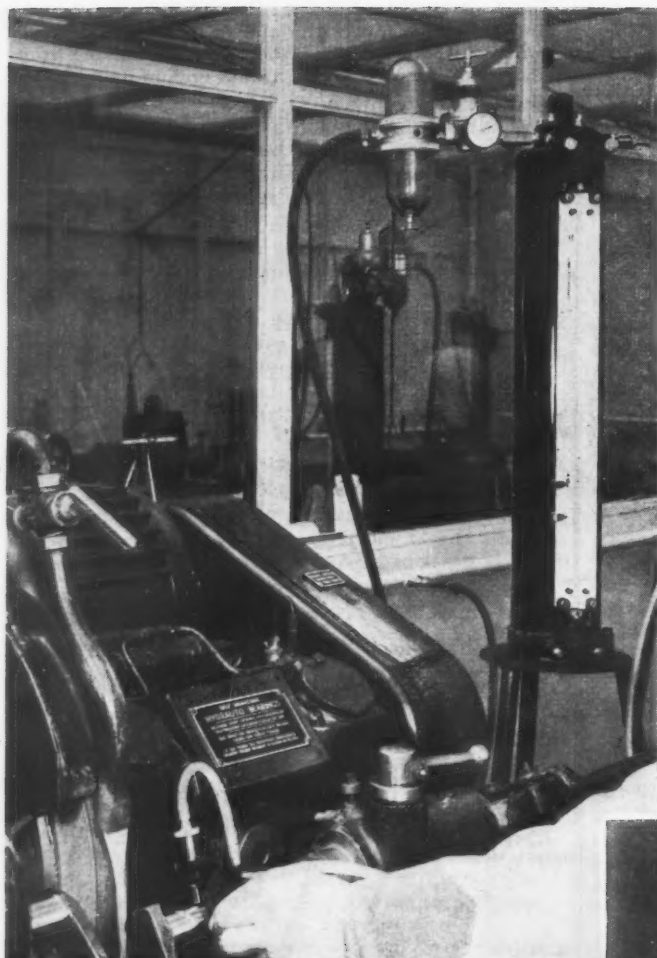
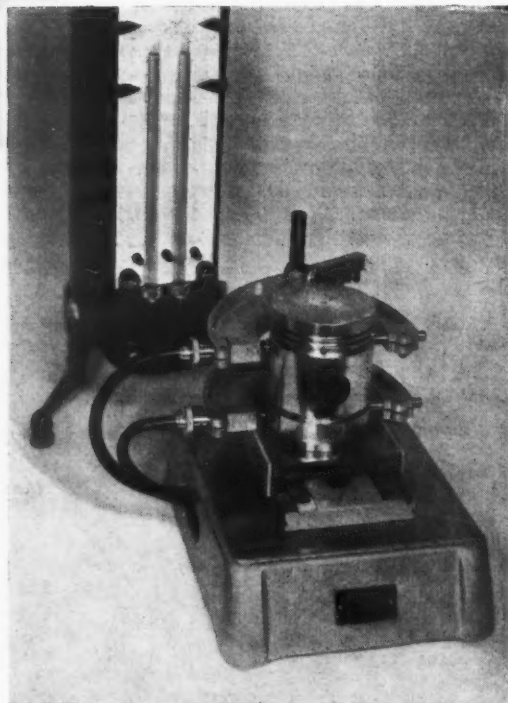


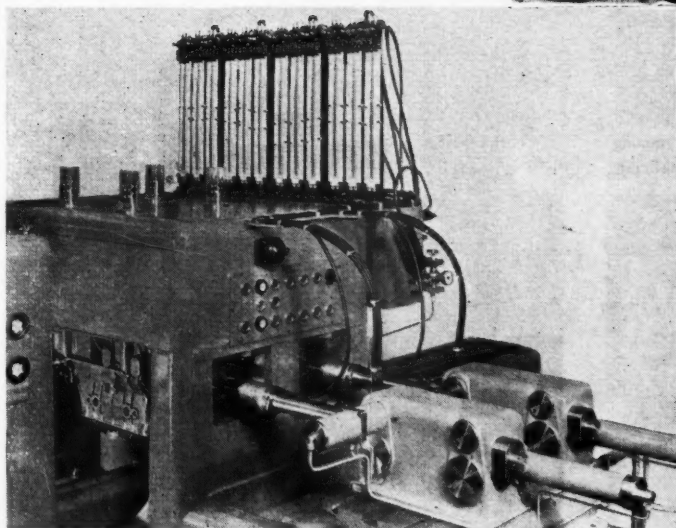
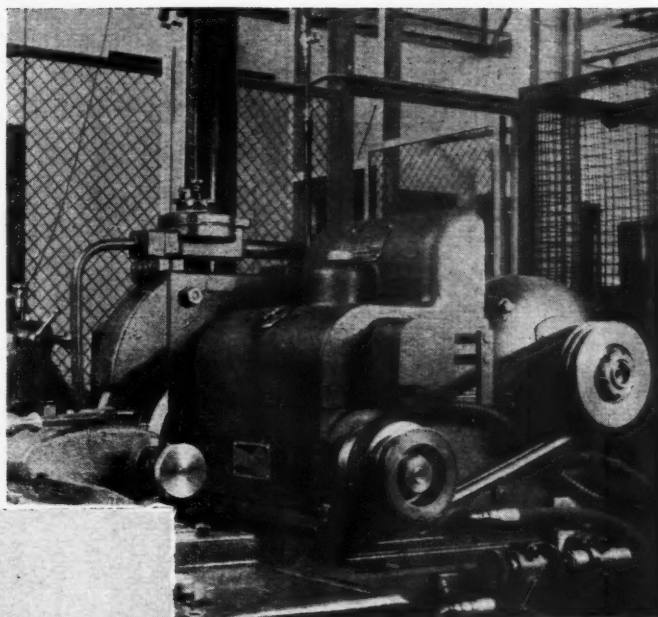
Fig. 16. Production type adjustable hand/snap gauge for measurement of crankshaft diameters on the machine.

Fig. 17. Production type measurement of piston skirt diameter at two positions beside the machine (after machining).

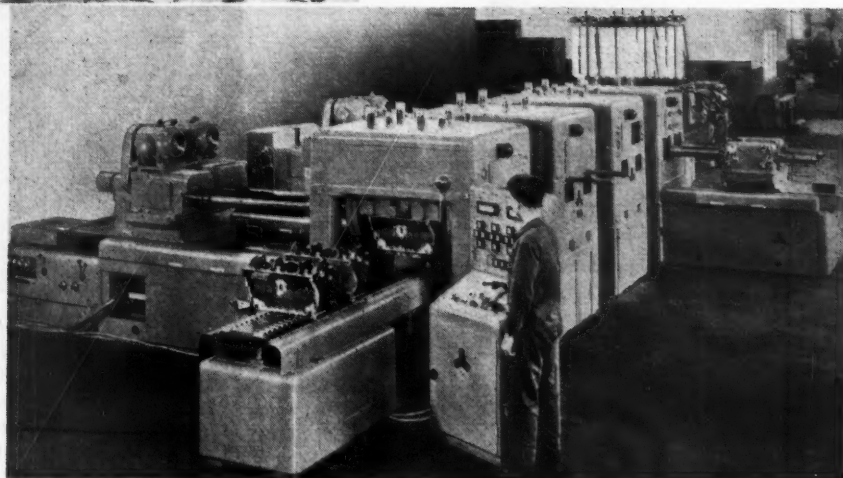




**Fig. 18 (right). Setting adjustment type feed gauge, for determination of wheel slide movement, mounted on external grinding machine.**



**Fig. 19 (left and below). Automatic machine control gauges incorporated in transfer machine, checking various bores. The machine stops if tolerance limits are exceeded.**



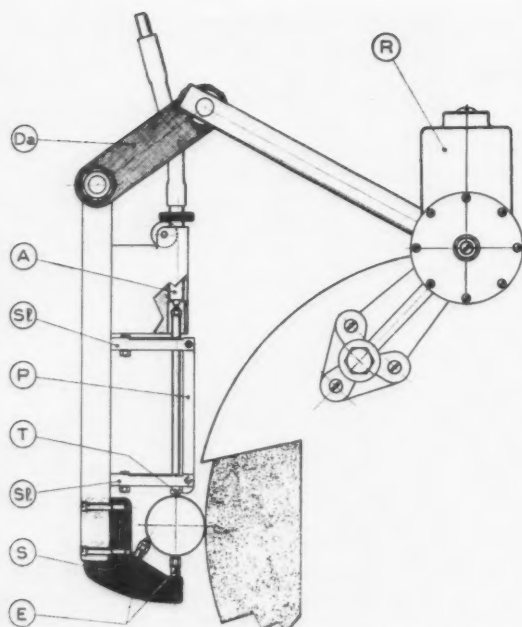
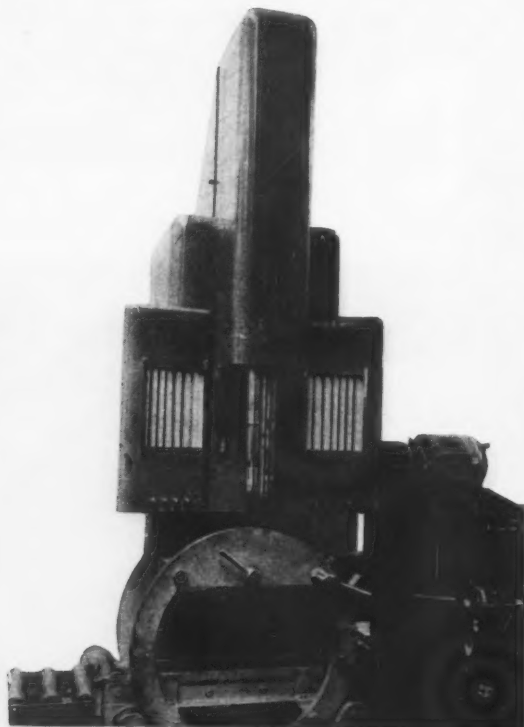


Fig. 20. Grinding caliper gauge used for sizing during grinding operation. The machine is stopped automatically when size is reached.



*Feed gauge:* a form of setting adjustment gauge where slide movements are used to produce the required dimension. (Fig. 18)

*Machine control:* the use of process gauges at/or on the machine—the using of both production gauge and setting gauge—often called Combined Gauging ascertaining dispersion and drift of tool wear and allowing early corrective action to be taken.

*Automatic machine control:* the use of a production gauge linked to the machine (sometimes first to signal them) to stop the latter when a given size (control limit) is found on any one or more usually a series of components (see *automatic sizing*). (Figs. 19 and 30)

*Automatic sizing:* a form of automatic machine control where the in-feed of the machine is slowed down and then stopped when a given dimension is reached during machining of an *individual* component. (Fig. 20)

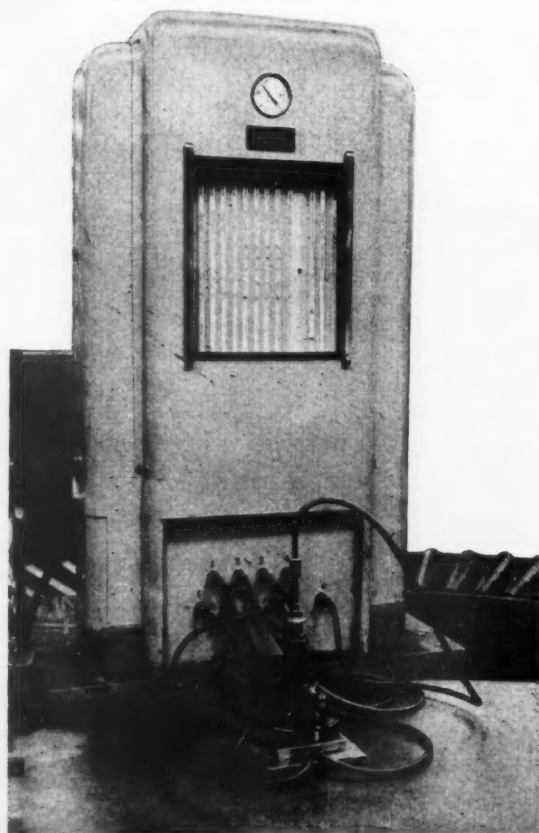
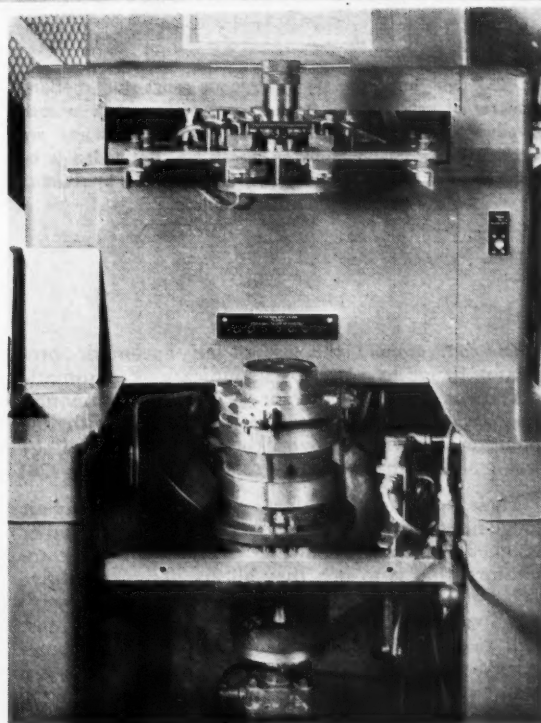
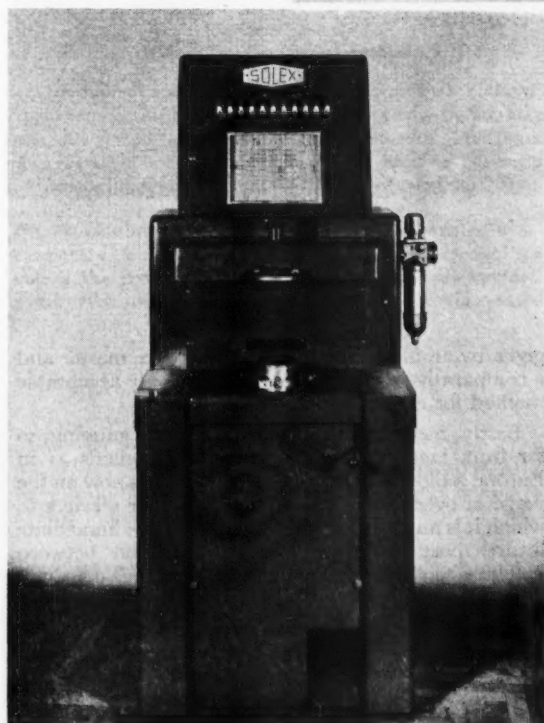
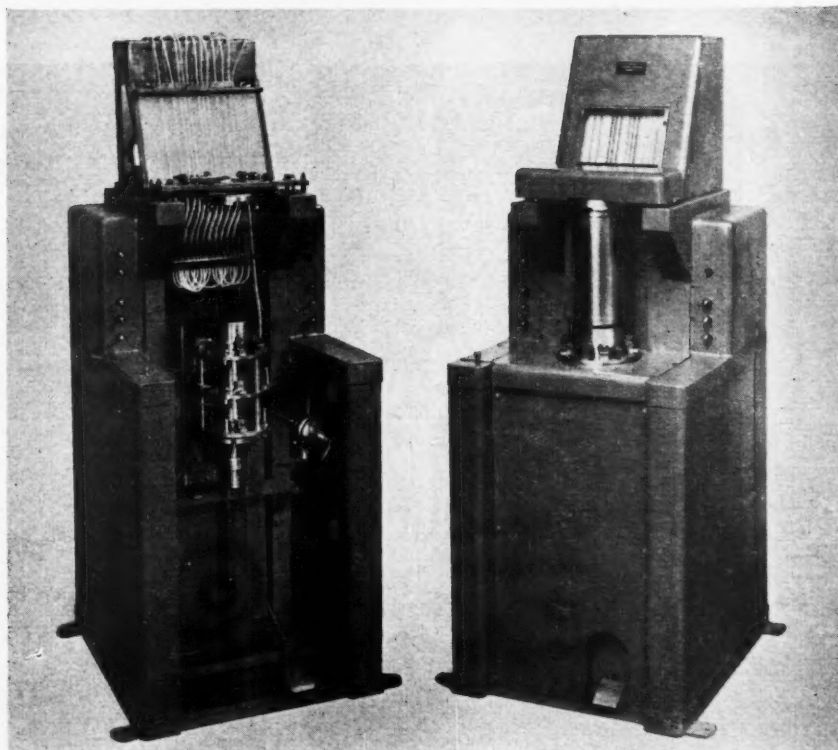


Fig. 21 (above). Line inspection—multi-table cabinet, checking oil pump body in nine dimensions.

Fig. 22 (left). Line inspection—multi-gauging installation in conveyor track line, gauging simultaneously all main bores, camshaft bores and alignment. Ovality is checked by rotation of gauging mandrel. Four and six cylinder blocks are accommodated by air-switch.

**Fig. 23. (Right) Line inspection — cylinder liner gauge checking bore, external diameter, flange diameter and thickness. (Left) With the panels removed the component is located on flange, and foot-pedal air cylinder operation allows gauge to enter component, thus indicating visual panel dimensional variations.**



**Fig. 24. Line inspection — a later development of multi-gauge for liner measurement, showing different construction of air ring gauge for checking the external dimensions of component. Operation is by foot-pedal, using standard air cylinder equipment.**

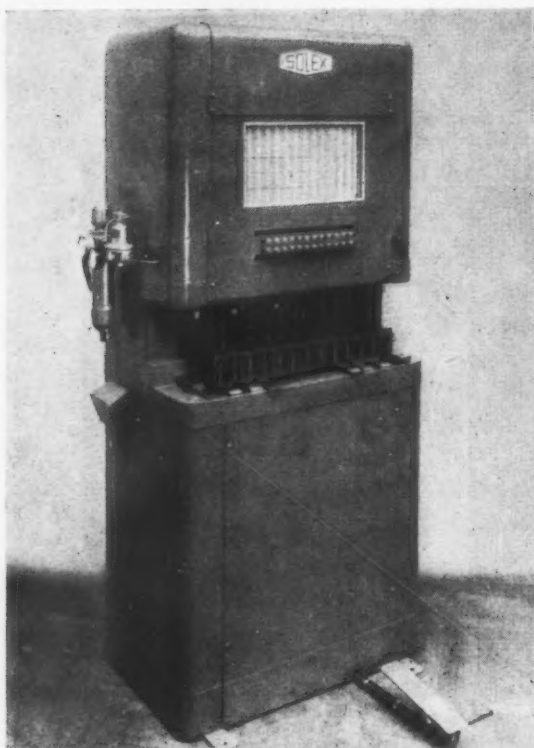


Fig. 25. Line inspection — 24-column gauge for checking diameter of valve guides (two measurements taken in each diameter) four or six cylinder, as required. Gauges are actuated into component by an air switch. Retraction is by foot-pedal (air cylinder) and ovality is determined by rotation of gauge, when required.

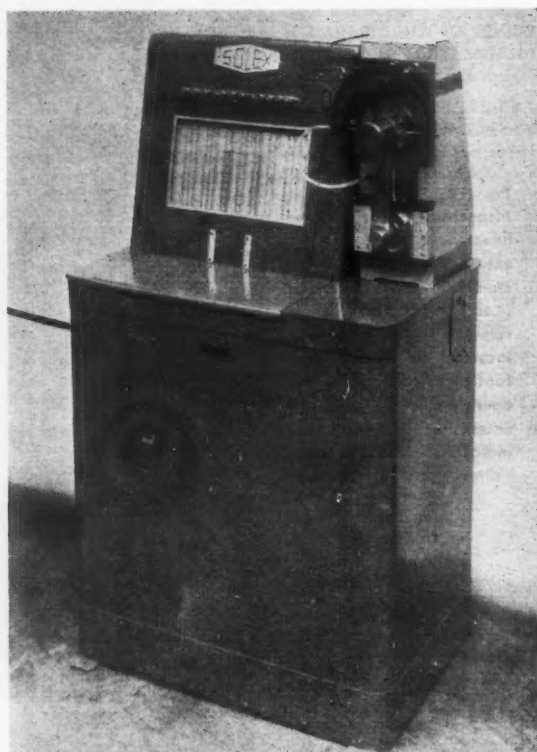


Fig. 26. Line inspection — multi-gauging application for conn-rod, checking simultaneously three-diameter positions, large bore three-diameter positions, small bore twist and alignment of both bores, external diameter of large end, and oil hole freedom from blockage in both bores.

*Feed-back control:* the use of an automatic production gauge to cause, by its indications, automatic movement of the machine or tool of a given amount, or to a given automatic setting gauge, with the intention of moving the size of the (usually, succeeding) part near the other side of the tolerance limits. (Fig. 20)

These examples are only a very few of the many air gauge installations which are extant, from many other designers in many countries. They are all comparators, that is to say, they all are designed to give a reading by comparison with a reference "master" of known size — not as an absolute size reading against their own inbuilt datum size or sizes. It has sometimes been said that such "absolute" gauges are what we should strive for and towards, as being a big step forward from the comparator. This may be so when the absolute gauge is really absolute, but there is no foreseeable date now when one could say that such gauges might be available. So long as any element of error or doubt can exist as to the size

given by an indicating gauge, a reference master and a comparative size reading will be the only acceptable method for every gauge user.

Lastly, metrology, and particularly air gauging, so far from lagging behind production methods as in Europe it did only a few short years ago, is now on the verge of overleaping the progress of other services to which it is an indispensable ancillary. The immediate future must see ever closer co-operation between machine-tool designer and gauge-designer, if we are not to fall behind other countries in the rate of our technical progress and independence in production and production methods. The compressed air industry can foresee the ever-increasing use of air gauges, carrying air into wider and fresh fields, bringing new problems but also new scope in its applications.

I have made no attempt to include a complete bibliography on air-gauging, as the available material is massive, much of it derivative in character, and



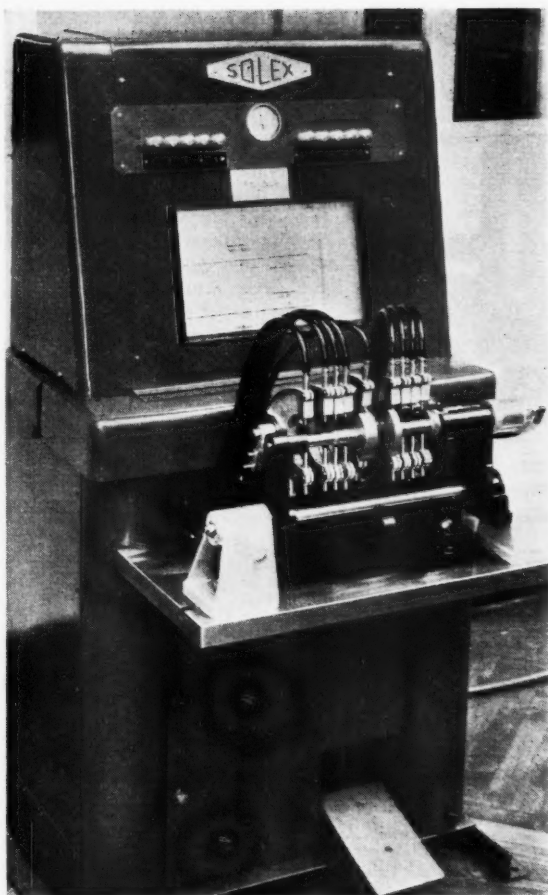


Fig. 27. Line inspection — crankshaft gauging installation — component located in pneumatically operated centres. To unload the component, the centres are retracted by foot-pedal. Nine diameters and one length check are gauged simultaneously.

some technically unsound in parts. The few references chosen, therefore, represent only what I have thought to be of special interest complementary to this Paper.

#### some references

1. French Patent 685416, British Patent 326674.
2. Marcel Mennesson — Methode de Mesure de Haute Precision des Longueurs et Epaisseurs — Comptes Rendus des Seances de l'Academie des Sciences 194- 1459-61. 25.4.32.
3. "Inspection in Industry," Anglo-American Council on Productivity Report, January 1953.
4. The Pneumatic Method Applied to Dynamic Measurement R. Yribarren. N.P.L., Symposium on Eng. Dimensional Metrology. 1953.
5. I.Prod.E. Paper — The Use of Comparators for Production. July 1952. (R. Yribarren and J. D. Richards).

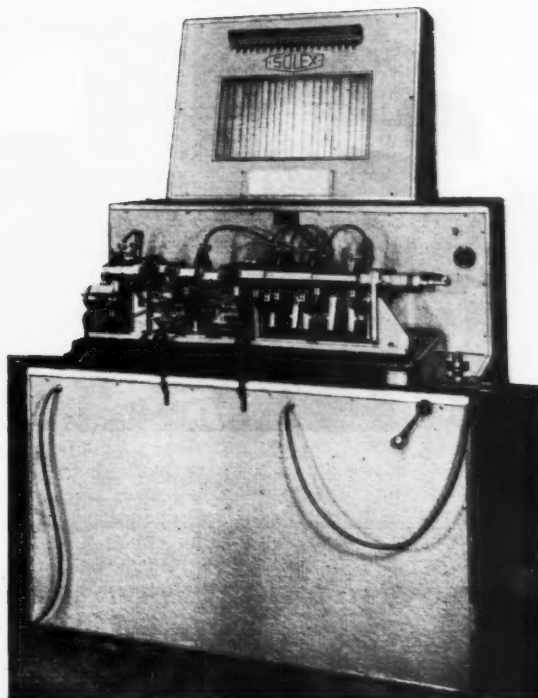


Fig. 28. Line inspection—a further development of crankshaft gauging. The component is located in vees by means of pneumatically operated roller clamps, and air cylinder equipment is applied for pressure on datum faces.

(SEE FIG. 29 OVERLEAF)



Fig. 29. Line inspection and grading — 24-column gauging installation for checking cylinder block bores, actuated throughout the air cylinder and switches. The component arrives at the brushing station where bores are cleaned; the location of the cylinder block in the gauging station actuates an air switch which lowers air jet plugs into bores. The grading is automatically stamped on the side of the component in situ.

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#### THE PRINCIPAL OFFICERS, 1958 - 1959 — continued

He left E.M.I. in 1953 to become Managing Director of High Pressure Components Ltd., West Drayton, and remained there until last year, when he established the Company of which he is now Chairman.

In addition to serving as a Member of the Institution's Council, Mr. Bowen is a Past President of the London Section, has served on the Education Committee, and was Chairman of the Programme Committee for the highly successful Conference held at Harrogate in 1957. He is also a Member of The Institution of Mechanical Engineers, and a Gold and Silver Medallist of the Junior Institution of Engineers.

#### The Vice-Chairman of Council

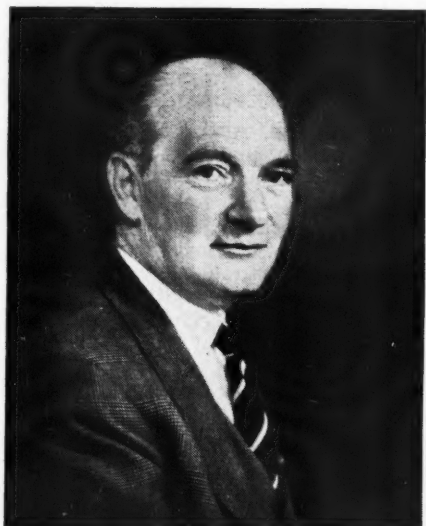
Mr. R. H. S. Turner, M.A.(Cantab.), M.I.Prod.E., has been elected Vice-Chairman of Council. Mr. Turner is Director and Works Manager of Metropolitan-Vickers Electrical Co. Ltd., Manchester.

The Principal Officers take office as from 1st July, 1958.

## THE PRINCIPAL OFFICERS, 1958 - 1959

### The President

The Council of the Institution announces with pleasure that The Rt. Hon. The Earl of Halsbury, F.R.I.C., F.Inst.P., M.I.Prod.E., has accepted an invitation to remain in office as President for a further year. The



Institution is indeed fortunate in having such an active President, who has visited many Regions and Sections during the year. In addition Lord Halsbury has been a regular attendee at Council meetings, and at the Finance and General Purposes Committee. His advice and guidance have been of very great benefit, the impact of which is likely to be felt throughout the future.

Lord Halsbury has been since 1949 Managing Director of the National Research Development Corporation, which was set up under the Development of Inventions Act, 1948, mainly to ensure the development and exploitation of inventions resulting from public research.

Born in 1908, Lord Halsbury was educated at Eton, and on leaving went into the City to study chartered accountancy. But he soon turned to science, and as an external student of London University took a B.Sc. degree with first-class honours in chemistry. His first industrial appointment was with Lever Bros., Port Sunlight.

During the War, at the research laboratories of Firth-Brown, in Sheffield, he worked on the design of special steels for the blades of gas turbines and jet engines. In 1946, he became Research Manager and later Works Manager of the Decca Record Co. Ltd., where his main research target was the production of gramophone records in unfilled plastic suitable for long playing records with silent surfaces.

Lord Halsbury was a Member of the Advisory Council of the Committee of the Privy Council for Scientific and Industrial Research from 1949 - 1954, and is now a member of its Mechanical Engineering Research Board. He has been Chairman of the Science Museum Advisory Council since 1951. He is also a Vice-President of the Parliamentary and Scientific Committee; Chairman of the National Institute of Industrial Psychology; Vice-President of the Royal Institute of Philosophy; and a member of the Court of Governors of the Manchester College of Science and Technology.

He is a Member of the Manchester Joint Research Council; a Member of Council of the Royal Society of Arts; and a Member of the Grand Council of the British Empire Cancer Campaign.

### The Chairman of Council

Mr. H. W. Bowen, O.B.E., M.I.Mech.E., M.I.Prod.E., has been elected Chairman of Council to succeed Mr. H. G. Gregory. Mr. Bowen has taken a leading part in the activities and development of the Institution since he became a member in 1934. Born at Criccieth, North Wales, in 1898, he is imbued with all the vigour, enthusiasm and shrewdness of the Welsh temperament, qualities from which the Institution will assuredly benefit during his term of office as Chairman.

Mr. Bowen, who is now Chairman of Damic Controls Ltd., Uxbridge, has had a spectacular career in industry. Following service as a Flying Officer in the Royal Flying Corps in the First World War, and an apprenticeship with the Montreal Water and Power Co., he joined the Canadian Electric Steel Co., in Montreal, as a mechanical draughtsman, subsequently moving to the Hall Engineering Co., Montreal, as Chief Draughtsman. He returned to the United Kingdom in 1923, and became Production Engineer with W. T. Glover, of Manchester.

Following similar positions with British Celanese Ltd., Derby, and the Ford Motor Co., in 1933 Mr. Bowen was offered, and accepted, an important appointment with Vickers-Armstrongs Ltd., at Barrow-in-Furness, who were responsible for the manufacture of battleships, cruisers, big guns and a variety of intricate mechanical and electrical equipment. He remained at Barrow until 1940, when he joined E.M.I. Factories Ltd., Hayes, as Joint General Manager (later Managing Director), thus achieving, as a comparatively young man, a very high appointment in British industry.

(continued on facing page)



## news of members

**Mr. H. B. Dauncey**, Member, has just completed 50 years' service with Messrs. T. H. & J. Daniels Ltd., Stroud, and to mark the occasion he was presented with a silver tea service and a cheque. Mr. Dauncey began his career with the Company as an apprentice, and has held successively the positions of Draughtsman, Chief Draughtsman, Assistant Works Manager, Works Manager, and Director of Special Projects. He is Chairman of the Western Section of the Institute of British Foundrymen.

**Mr. J. D. Joy**, Member, will relinquish his position of General Works Manager at Samuel Fox on 31st August, and will move to Appleby-Frodingham as a Director and General Works Manager, with a view to becoming Deputy General Manager on 1st January, 1959.

**Mr. J. G. Miller**, Member, General Works Manager of Hardypick Ltd., has now retired.

**Mr. J. R. Moore**, Member, has been appointed Director and Divisional Manager of the Fisher Governor Company, which is a subsidiary of Elliott Automation.

**Mr. W. Winters**, Member, Director and General Manager of the Coventry Victor Motor Company for the past seven years, has been appointed a Director of the Triumph Engineering Co. Ltd., Coventry.

**Mr. F. O. Ackroyd**, Associate Member, has been appointed to the Board of Crofts (Engineers) Ltd.

**Mr. J. W. Dunford**, Associate Member, Chief Designer, has been appointed to the Board of Directors of Highfield Gear & Engineering Co. Ltd., Huddersfield. Mr. Dunford will continue in his position of Chief Designer.

**Mr. D. Hitchings**, Associate Member, has relinquished his position of Work Study Engineer with the Glacier Metal Company and has taken up an appointment as Chief Instructor (Work Study) with British Railways (London Midland Region).

**Mr. J. J. Lynam**, Associate Member, who has for many years represented John Lund Ltd., is also to represent Stanley Machine Tool Co. Ltd., New Bank, Halifax, and Maiden & Co. Ltd., Hyde, Cheshire. He will cover Lancashire and the North West area.

**Mr. S. M. Maude**, Associate Member, has been appointed Works Manager of Anderson Springs and Dee Kay Ltd.

**Mr. J. Raeside**, Associate Member, has now left Hurst Nelson Company, Motherwell, and has taken up a position with The Rivet Bolt & Nut Company, Seatia Works, Rutherglen.

**Mr. R. G. Richardson**, Associate Member, has recently been elected a Member of the American Society of Automotive Engineers.

**Mr. R. H. Seally**, Associate Member, has recently relinquished his position of Technical Sales Engineer with W. E. Sykes Ltd. (Australian Branch) and has taken up an appointment of Methods Engineer with A.E.I. Pty., the Australian Associate of B.T.H. and Metropolitan-Vickers Electrical of England.

**Mr. W. P. Shead**, Associate Member, has been appointed Lecturer and Consultant with the Engineering & Allied Employers' West of England Association.

**Mr. James F. Spencer**, Associate Member, has been promoted Lecturer responsible for Production Engineering in the Department of Mechanical Engineering at Doncaster Technical College.

**Mr. A. W. Wentworth**, Associate Member, has recently relinquished his position with the Technical Enquiry Service of PERA and has now joined the Sperry Gyroscope Co. (Bracknell Division) as Chief Jig and Tool Draughtsman.

**Mr. B. L. J. Hart**, Associate, has recently left the Department of Work Study and Staff Training of the Engineering & Allied Employers' West of England Association, to take up a position in the Computer Section of The British Tabulating Machine Co. Ltd. Mr. Hart was responsible for developing training courses in Production Planning and Control in Bristol.

**Mr. T. R. Knowles**, Graduate, has taken up an appointment of Assistant Lecturer Grade 'B' in the Production Engineering Department of the Harris College of Further Education, Preston.

**Mr. P. B. Nair**, Graduate, has relinquished his position as Industrial Consultant, Beacons (P) Ltd., and is now Assistant Works Manager, Asbestos Cement (Private) Ltd., Bombay.

**Mr. M. J. Walsh**, Graduate, has taken up an appointment with The English Electric Co. Ltd. at Liverpool, as Chief of Production Control, Domestic Appliance Works. Mr. Walsh has just returned from the U.S.A. after a short visit to study methods employed there in this particular field.



## Obituary



**Mr. F. T. NURRISH, M.B.E., M.I.Prod.E.**

ON 8th May, 1958, Mr. Frederick Thomas Nurrish, M.B.E., died at the age of 61, and The Institution of Production Engineers, in common with other educational and industrial institutions (particularly in Yorkshire) suffered the loss of one of its most active workers.

Starting as an engineering apprentice with J. H. Tucker & Co. Ltd., of Birmingham, his subsequent career established for him a reputation, first as a designer of special machinery and equipment, and afterwards as a production engineer, works manager and director.

He joined George Bray & Co. Ltd. in 1920, and was appointed to the Board of George Bray & Co. Ltd. and of Bray Accessories Ltd. in August, 1942. On the death of Colonel George Bray he became joint managing director of those companies in January, 1952.

He devoted considerable time to work for the Institution, was a Member of the Yorkshire — afterwards the Leeds — Section Committee for many years; was Past President of the Yorkshire Section, Past Chairman of the East and West Ridings Region and gave invaluable help as a member of the Conference Organising Committee. He took keen interest in the work of the Institution Research Committee of which he was a past member. At the time of his death, Mr. Nurrish was a member of Council.

In spite of his many industrial activities he always found it possible to devote a considerable amount of time to young peoples' organisations.

In any work that Fred Nurrish undertook he was enthusiastic, thorough, and never content until all details had been decided upon and the work in hand proceeded with as quickly as possible.

In later years he suffered severely with chest troubles and those of us who knew him well were always deeply impressed by the cheerful manner in which he endured his physical difficulties.

The Institution and other organisations in which he was interested will certainly miss his help and wise counsel.

J. E. HILL.

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### FINANCING OF ADVANCED SANDWICH COURSES

Since the White Paper on Technical Education was published in February, 1956, the number of advanced sandwich courses, under which students spend part of the year in a technical college and part in industry, has increased from 100 to over 200, and the number of students taking them from 2,000 - 3,000 to 5,000 - 6,000. The objective is to raise the number of students to 15,000 - 20,000, and so contribute to the building up of the supply of technologists which the country needs.

With a view to stimulating the spread of these courses, particularly among medium-sized and small firms, the Ministry of Education and the Federation of British Industries have been reviewing the arrangements for giving financial assistance to students who wish to take them.

The Federation of British Industries, in a policy statement issued recently to all members, stated its belief that industry, by enabling selected employees to

pursue advanced sandwich courses, in addition to supporting day release schemes, acted in its own as well as in the nation's interest. The Federation recommended to its members that firms which already pay their students' fees and salaries should continue to do so, and expressed the hope that firms sending students on advanced sandwich courses in the future would follow this example, since it stimulated the student's sense of loyalty to the firm and strengthened the firm's ties with the college. Such payments were treated as normal business expenses for tax purposes.

The Ministry and the Federation recognise, however, that there are and will continue to be firms who do not feel able to meet the whole cost of such training. There will, therefore, be a continuing number of such students who will look to local education authorities for aid. In a memorandum issued at the same time, Mr. Geoffrey Lloyd, the Minister of Education, recommended local education authorities to give sympathetic consideration to such applications.

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## ADDITIONS

- Aluminium Development Association, London. "A Symposium on Aluminium and its Alloys in Electrical Engineering . . . London, May, 1957." London, the Association, 1957. 369 pages. Illustrated. Diagrams. 20s. Contents: Session 1 — General and economic considerations in using aluminium in electrical engineering — Economics of aluminium in electrical engineering — Aluminium and its alloys in electrical engineering — Fundamentals of jointing processes for aluminium. Session 2 — Aluminium in transmission and distribution lines — Aluminium for overhead distribution lines — Medium and low voltage insulated aluminium conductored cables for the distribution of electricity. Session 3 — Aluminium in electrical equipment — The use of aluminium in the construction of transformers — Aluminium and aluminium alloy busbars — Aluminium in telecommunication cables — Aluminium in the British telephone service — French experience with aluminium conductors in electrical equipment — German experience with aluminium electrical equipment. — Aluminium conductors applied to electrical transmission lines in Italy — The use of aluminium strip conductor in electrical equipment.
- Anderson, Chester Reed, and others. "Business Reports : Investigation and Presentation" by Chester Reed Anderson, Alta Gwinn Sanders and Francis William Weeks. 3rd edition. New York, London, etc., McGraw-Hill, 1957. 407 pages. Diagrams. 46s. 6d. A comprehensive textbook on the production of business reports of various lengths and kinds. It includes advice on the collection of data, the orderly arrangement of information, on literary style, and on layout and other aspects of physical presentation. There are useful sections on the preparation and presentation of bibliographies and indices, which, while not long enough to do more than indicate the principles and demonstrate some of the routine of these tasks, should stimulate the reader to undertake them carefully and methodically. Much of the book is devoted to the fundamentals of clear writing and orderly thinking and so repeats what has been written in many textbooks of language and elementary logic. The book is nevertheless a useful compendium and guide.
- American Society of Tool Engineers, Detroit, Michigan. "Collected Papers, 1957." Technical Papers and Panel Conferences presented at 25th anniversary meeting. Detroit, the Society, 1957. 43 parts in folder. Illustrated. Diagrams. £5. Contents:  
Polk, Louis — "Heritage and Growing Abundance" (First Eli Whitney Memorial Lecture).  
*Registration Benefits to the Tool Engineer in Industry*  
Andrews, W. M. — "The 'Why' of Registration and the Benefits Accruing."  
Thomas, C. Y. — "Registration: Industry's Point of View."  
*Management and the Tool Engineer*  
Belcher, Herbert R. — "Labour Control Experience in Aircraft Repair."  
Scharff, S. E. — "Some Economic Aspects of Machine Tool Selection."  
*Engineering Behind and Earth Satellite Launching*  
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Sipe, Raymond G. — "Tool Engineering for Project Vanguard."  
*Designer-Tool Engineer Co-operation*  
Halverstadt, R. D. — "Design for Machining Heat Resistant Alloys."  
Wennberg, Jens L. — "Chip-breaking Characteristics of Titanium."
- Stresses and the Tool Engineer*  
Henrikson, Erik K. — "Residual Stresses from Machining Operations."  
Harrington, John A. — "Stress and High Temperature in Grinding."  
*Rolling Technique*  
Appleton, Clifford T. — "Fundamentals and Application of Thread and Form Rolling."  
Bergman, J. W. — "Another Revolutionary Process — Power from Rolling."  
*Tool Design*  
Ellis, John L. — "A Machineable Heat Treatable and Weldable Cemented Carbide for Tooling Purposes."  
Rubenson, J. G., and Butterworth, G. S. — "The Inchwork Motor."  
*Machine Tools in the Oil Industry*  
"Ridgway, W. F. — "Special Machine Tools for the Oil Country."  
Noble, Wiley B. — "Threads that Hold the String Together."  
*Ceramic Tool Symposiums*  
Rea, Robert F. — "Background and Properties of Oxide Cutting Tools."  
Cook, N. H. — "A Review of Published Russian Work."  
Moore, H. D., and Smith, P. A. — "A Comparison of Workpiece Finishes Produced by Ceramic and Carbide Tools."  
Cook, N. H. — "Cutting Tool Temperatures."  
Allen, J. F. — "Ceramic Cutting Tools Applied to Production Jobs."  
Kibbey, D. R., and Morris, W. T. — "Analysis of Variables in Ceramic Tool Cutting."  
Haeme, Alfred O., and Hook, Robert T. — "Industrial Application of Ceramic Tools."  
Weller, E. J. — "Cemented Oxide Cutting Tools in Service."  
Kennedy, W. B. — "Experimental Machining with 'Ceramics.'"  
Engle, E. W., and Barnes, G. W. — "Ceramic Tools: the Challenge of Physical Properties."  
Zlatin, Norman — "Ceramic Machining Developments at Wright Aeronautical Division, Curtiss-Wright Corporation."  
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Lindgren, V. V. — "What are Plastics?"  
Dorman, Elliott N. — "What Properties are Available in Plastics?"  
Juras, Appy. — "The History of Plastic Tooling."  
Oye, Lloyd J. — "The Fabrication of Plastic Tools."  
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Weaver, William — "Known Limitations of Plastic Tooling."  
Rice, George M. — "Can Plastic Tools be Repaired and Modified?"  
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Sokol, Benjamin. — "Repair and Modification of Plastics Tools."  
Arrufat, Walter J. — "Plastic Tooling for Small Parts."  
Ruddiman, Edsel — "Experiences with Plastic Tooling in the Stamping Plant."  
Price, W. Robert, and Peerman, D. E. — "Polyamide Resin Alloys in Practical Tooling Applications."  
*Standards and the Tool Engineer*  
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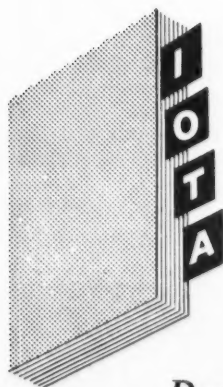




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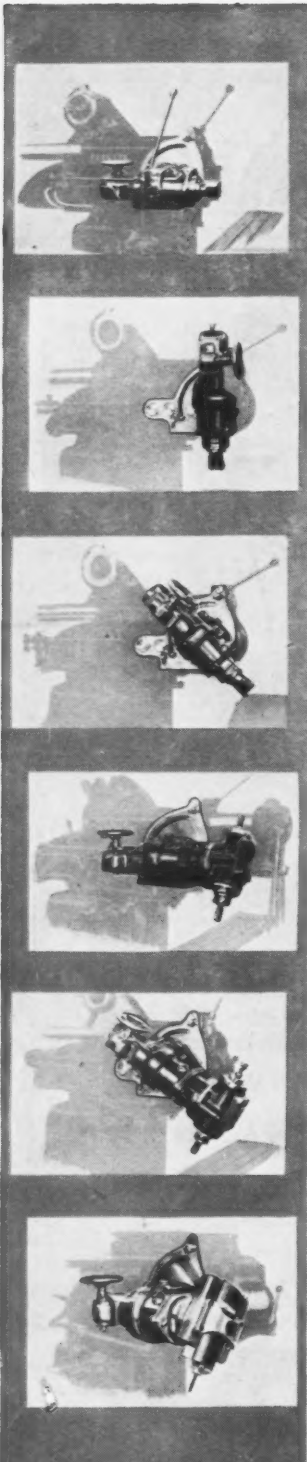
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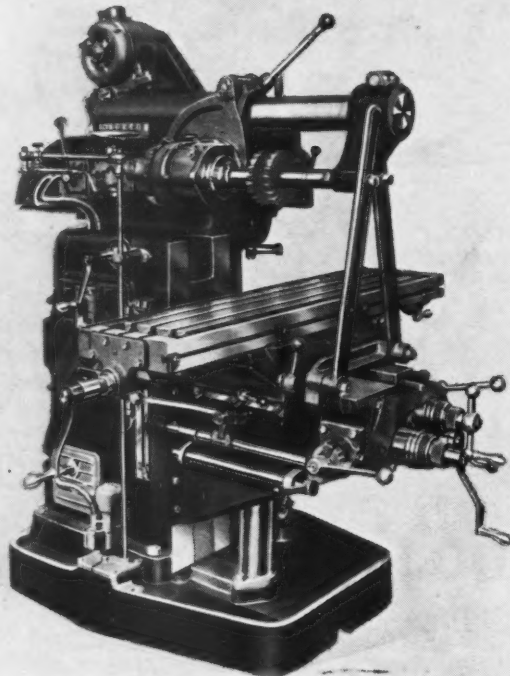
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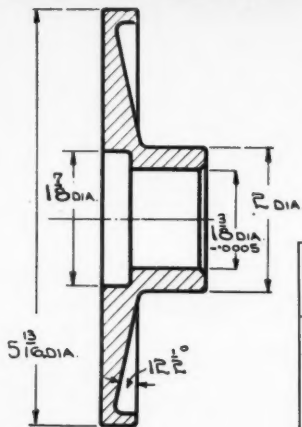
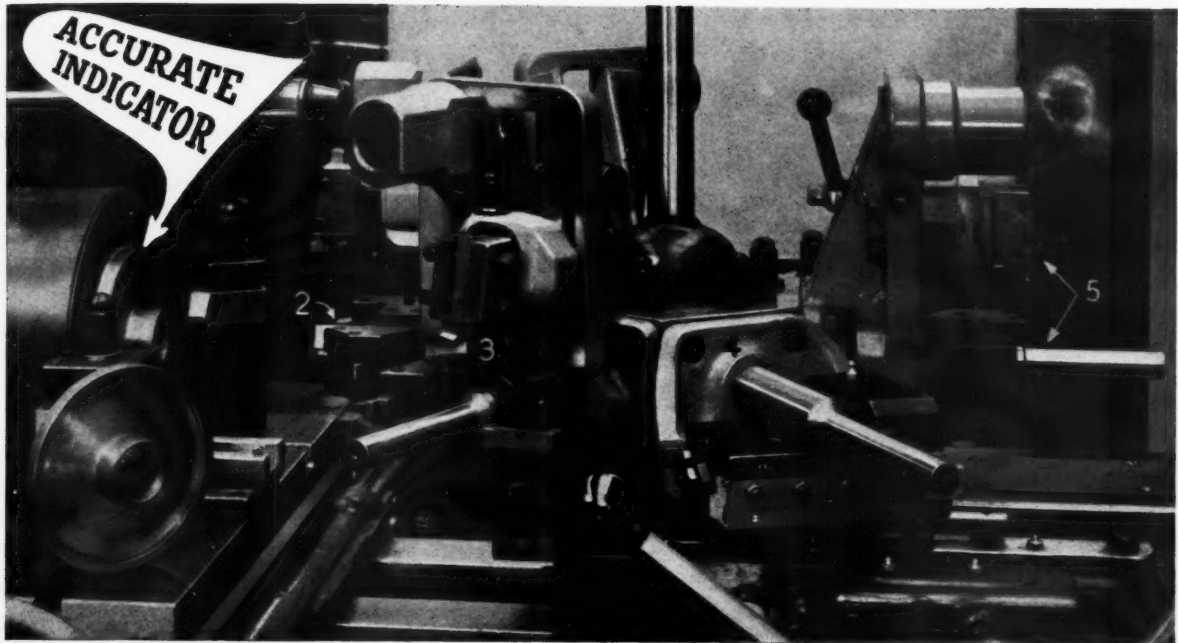
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FITTED WITH 200 mm. 3-JAW AIR CHUCK

DESCRIPTION OF OPERATION	Tool Position		Spindle Speed R.P.M.	Surface Speed Ft. per Min.	Feed Cuts per inch
	Hex. Turret	Cross-slide			
1. Chuck on 0/dia. - - - -	—	—	—	—	—
2. Double Face - - - -	—	Rear	260	405	Hand
3. Rough Bore 1 1/8", Turn 2" and 5 1/8" dia.	1	—	260	405	125
4. Bore inside Rim and Radius Boss -	2	—	358	515	125
5. Turn Boss and Angle Face (2 cuts)	3	Centre	358	515	128
6. Finish Turn 0/dia. Face & Chamfer Boss	4	—	358	545	125
7. Reverse Component in Chuck Jaws	—	—	—	—	—
8. Bore 1 7/8" and 1 3/8" dias. - - -	5	—	260	405	{ 125 128 125
9. Rough and Finish Face - - -	6	Front			
10. Microbore 1 3/8" dia. - - -	—	—	954	343	125
10. Remove.	—	—	—	—	—

Floor-to-Floor Time: 6 mins. each

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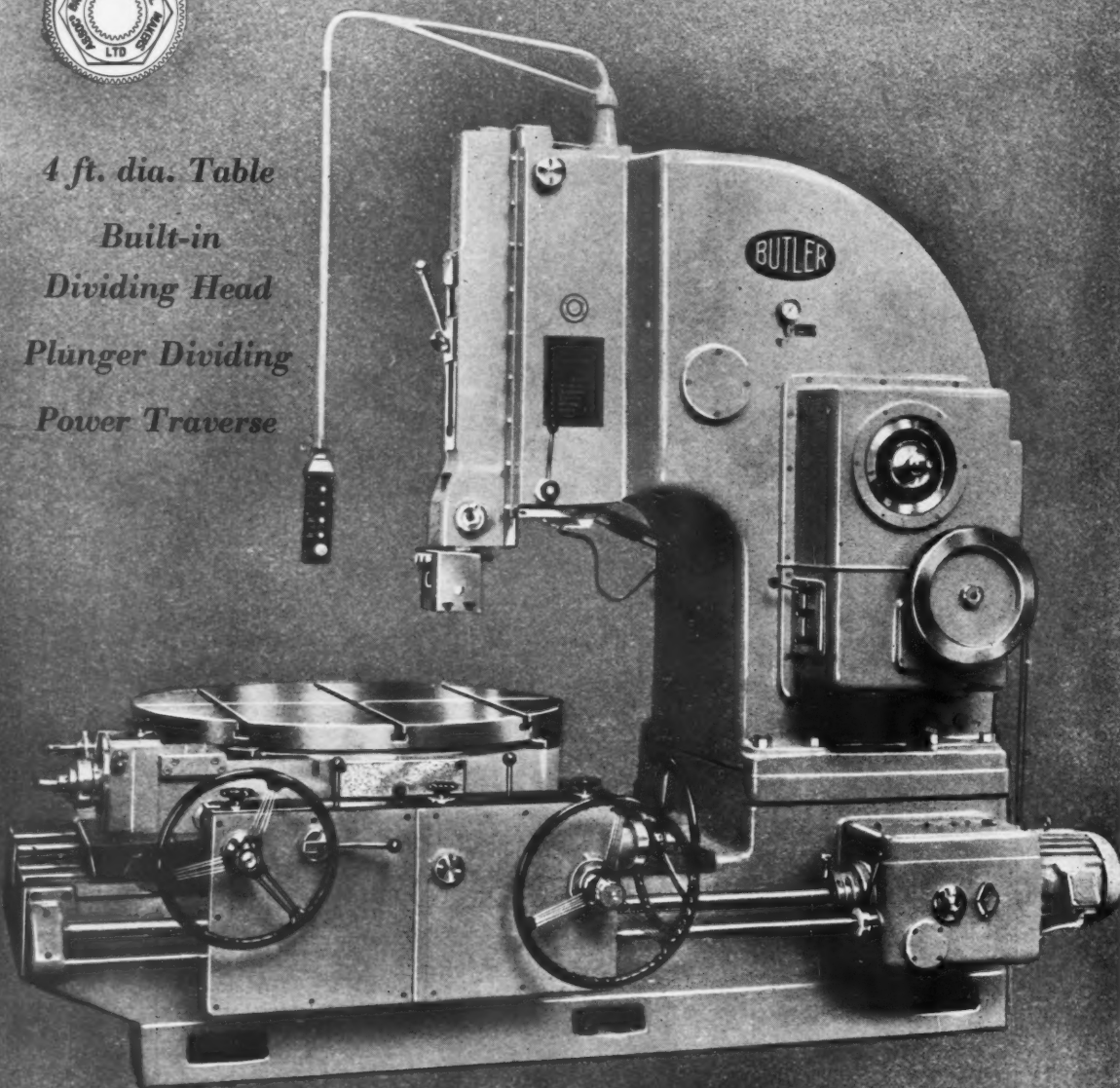
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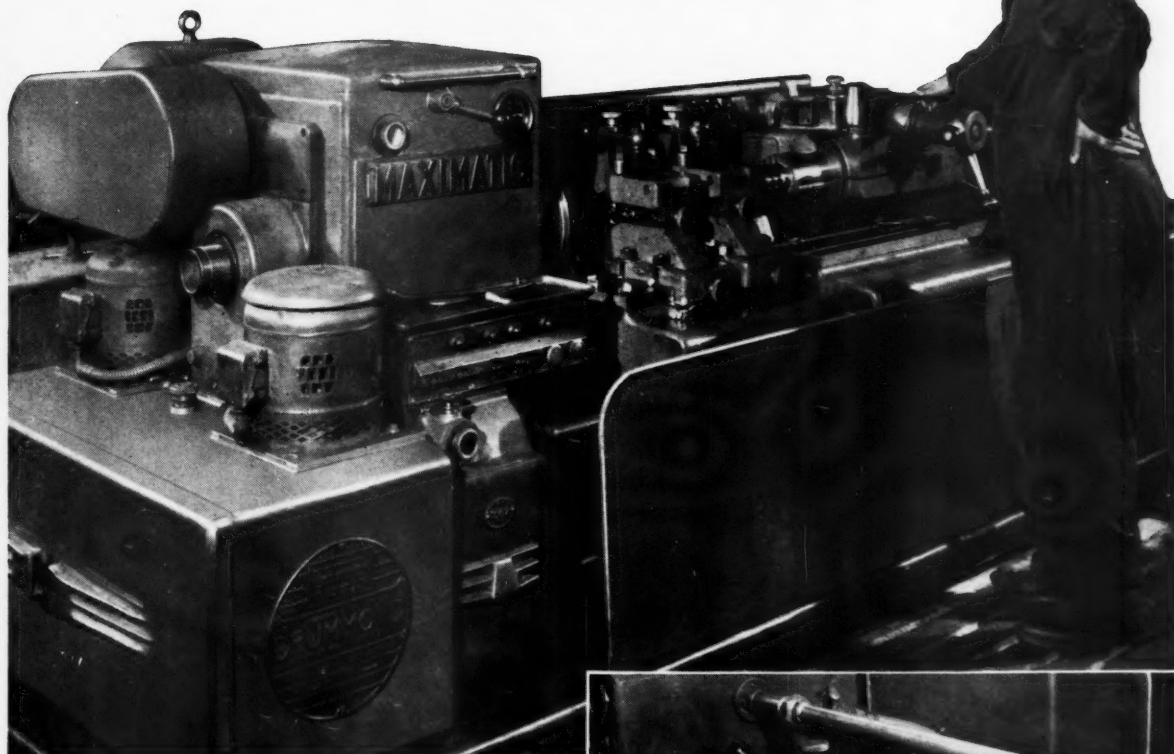
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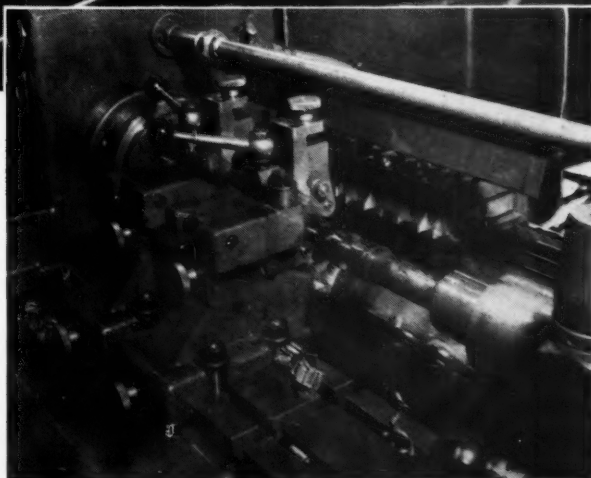
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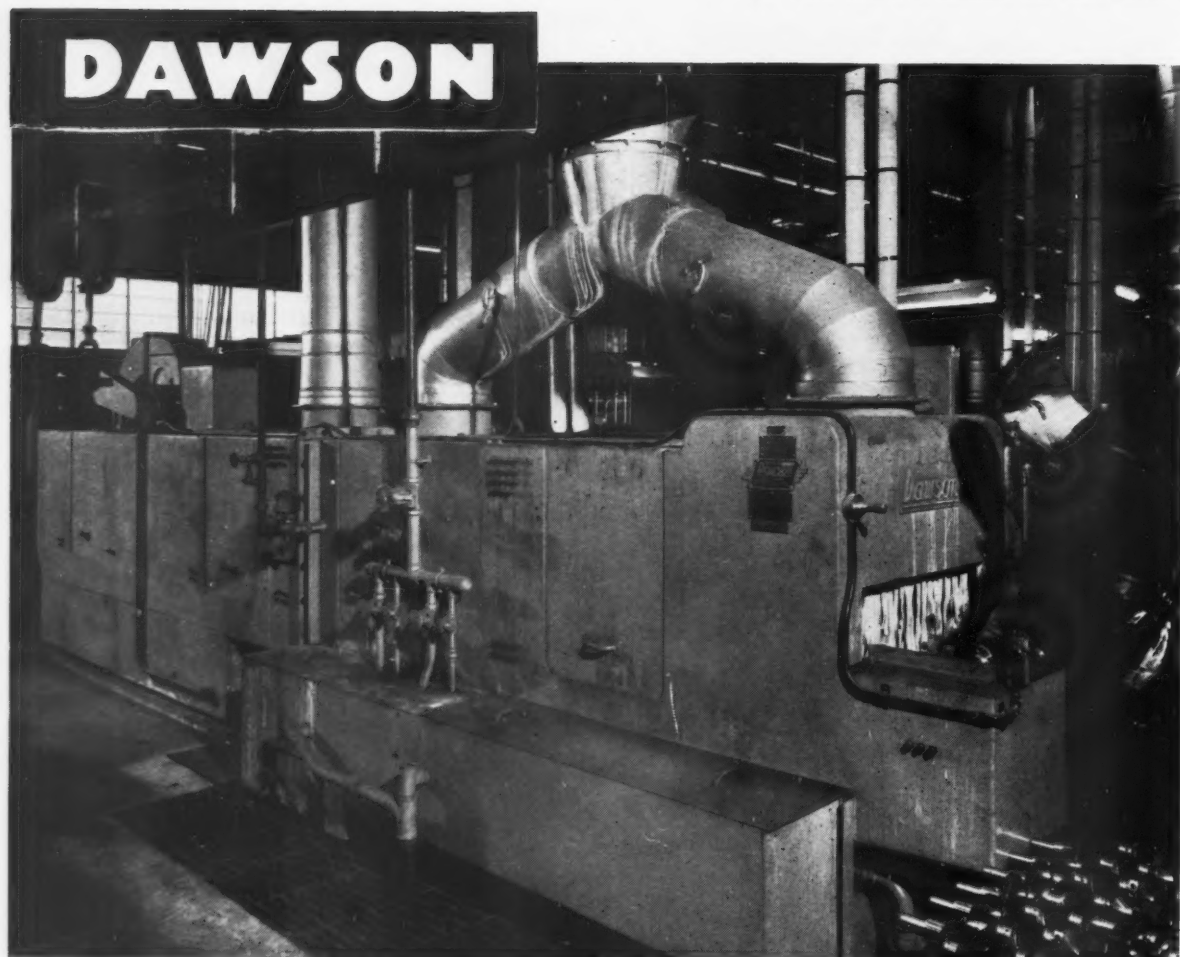
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HF 273





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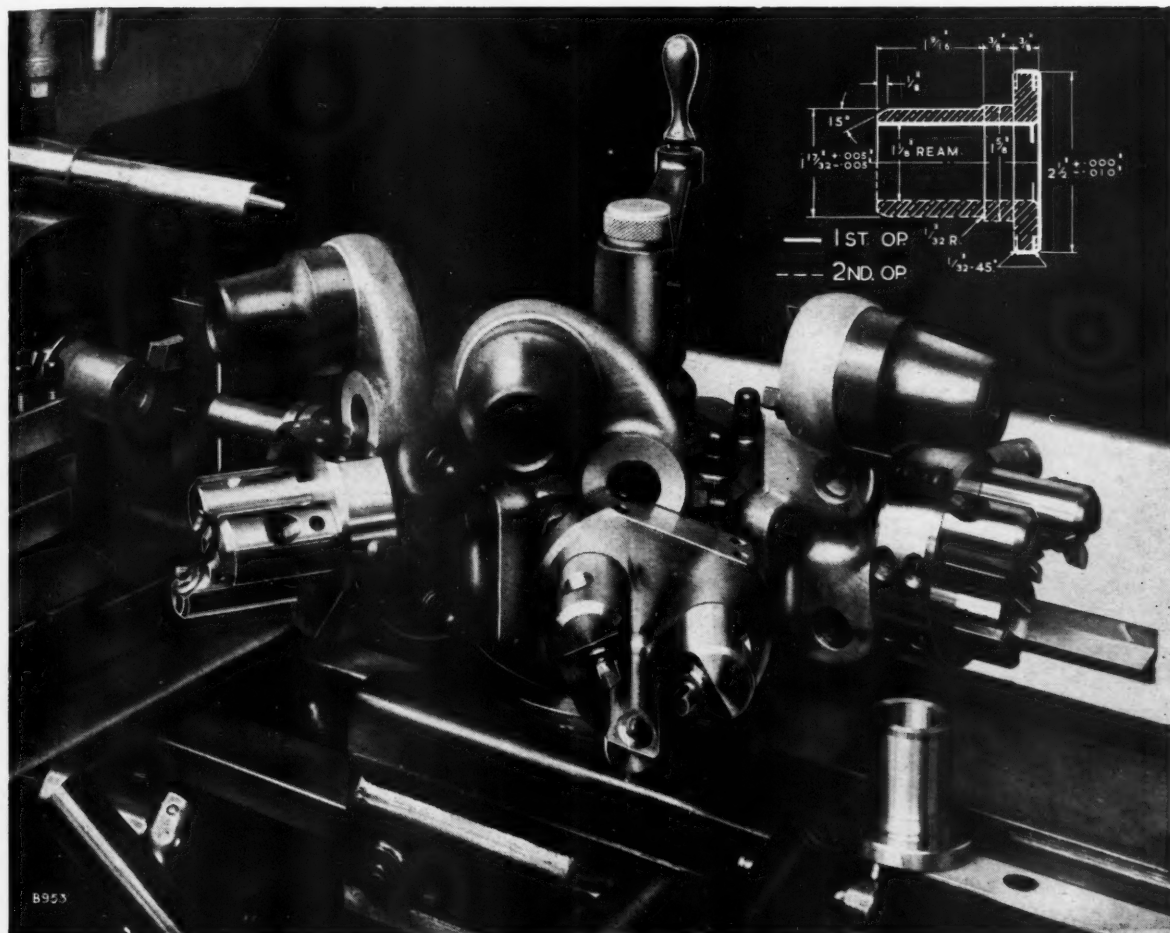
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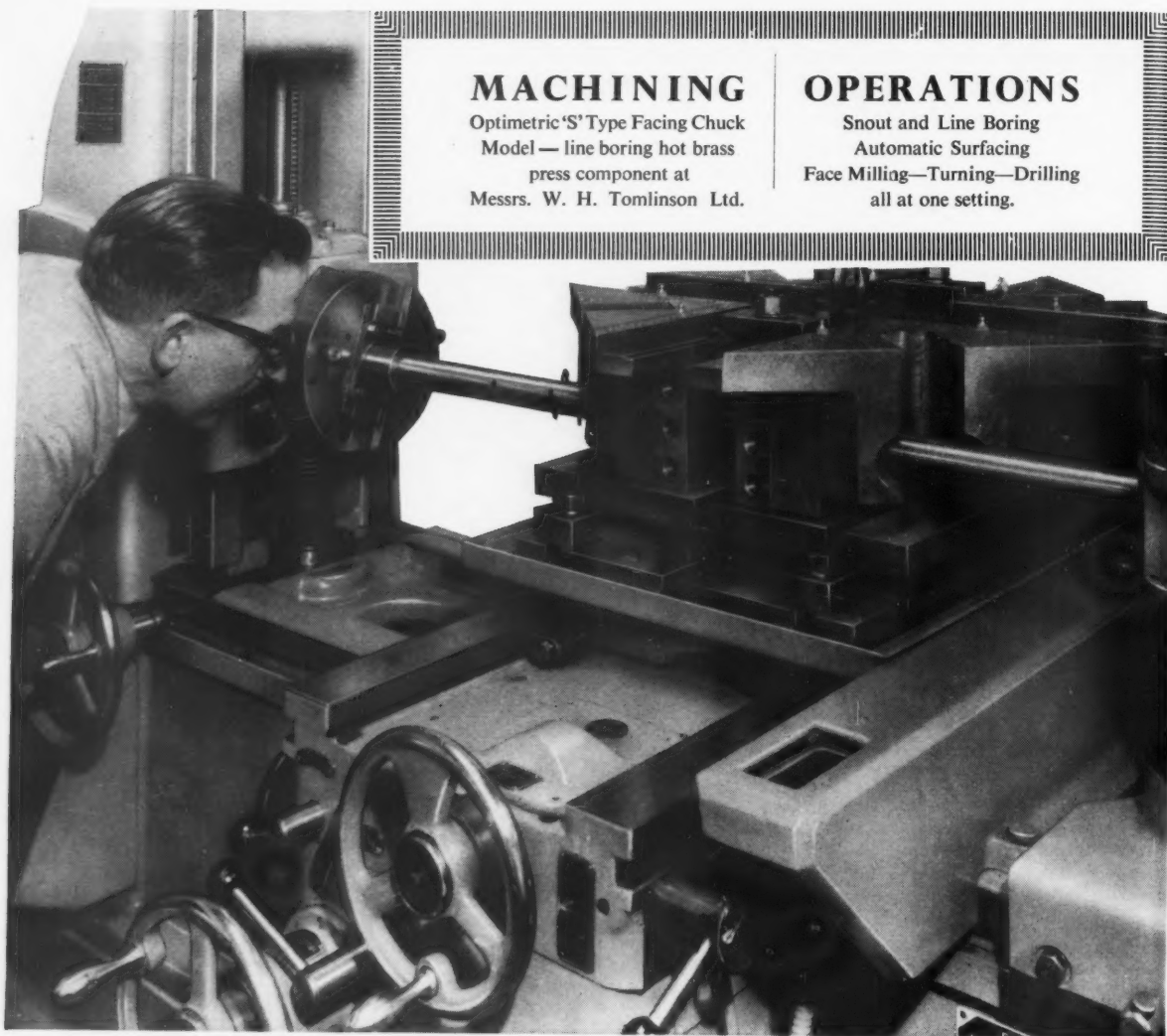
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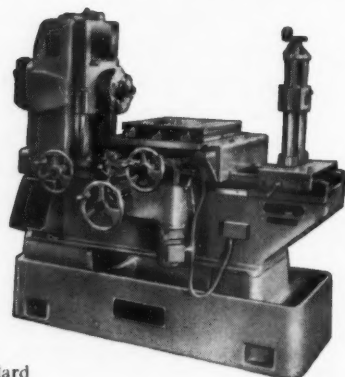
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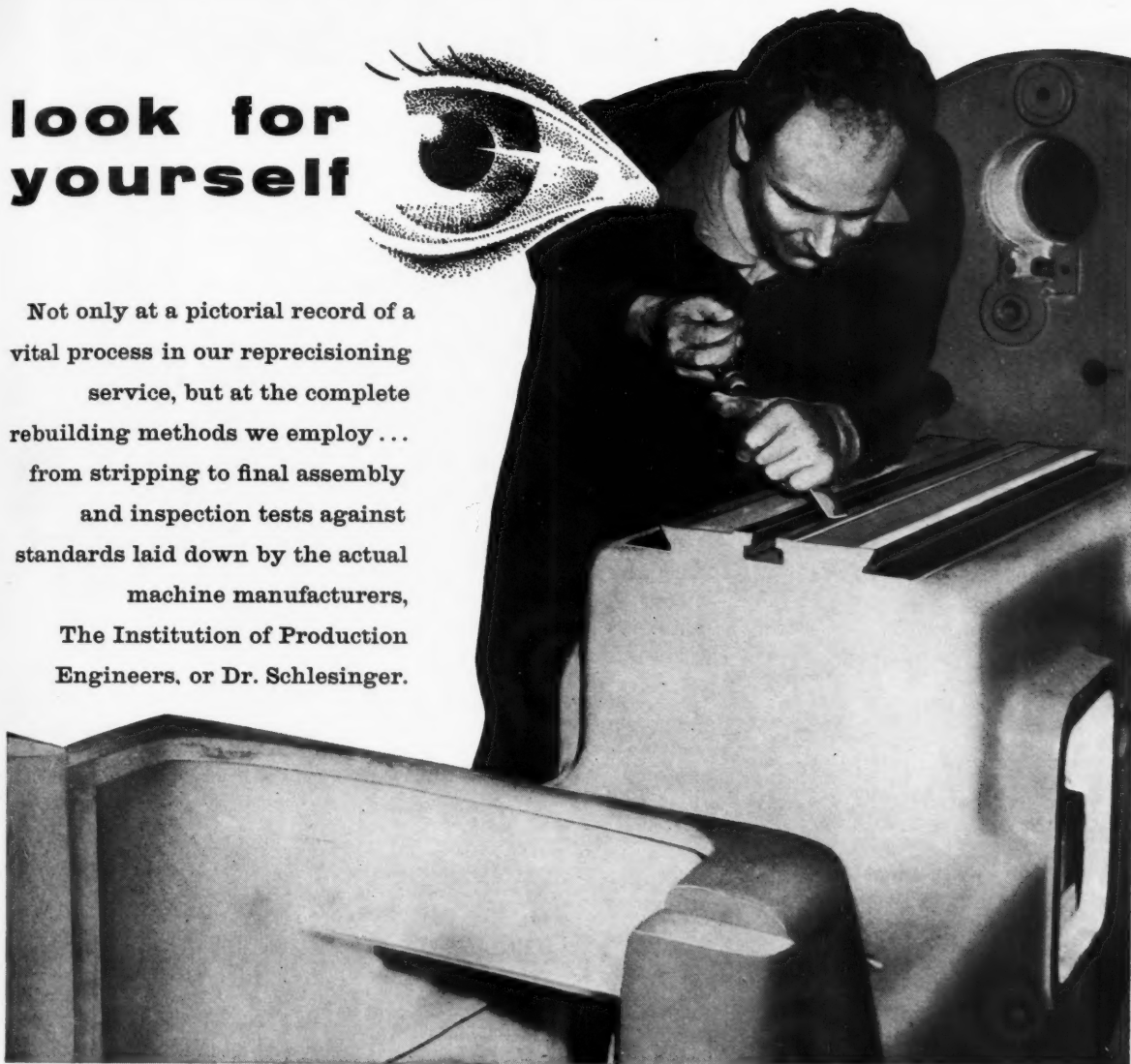
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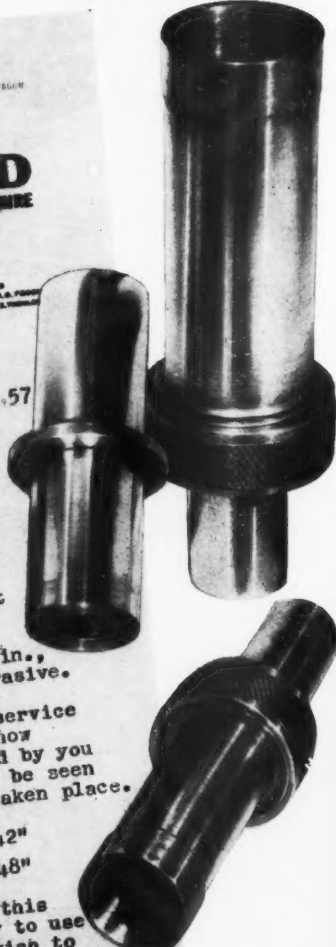
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In January 1955 you supplied us with two shot blast nozzles in Carbon Tetra Boride. These were immediately put into use in the shot blast cabinets in our Heat Treatment department, working at an air pressure of 40 to 60 lbs/sq. in., and using 30 mesh angular chilled cast iron grit as the abrasive.

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Bore Size at Throat of Nozzle	.3745" to .3742"
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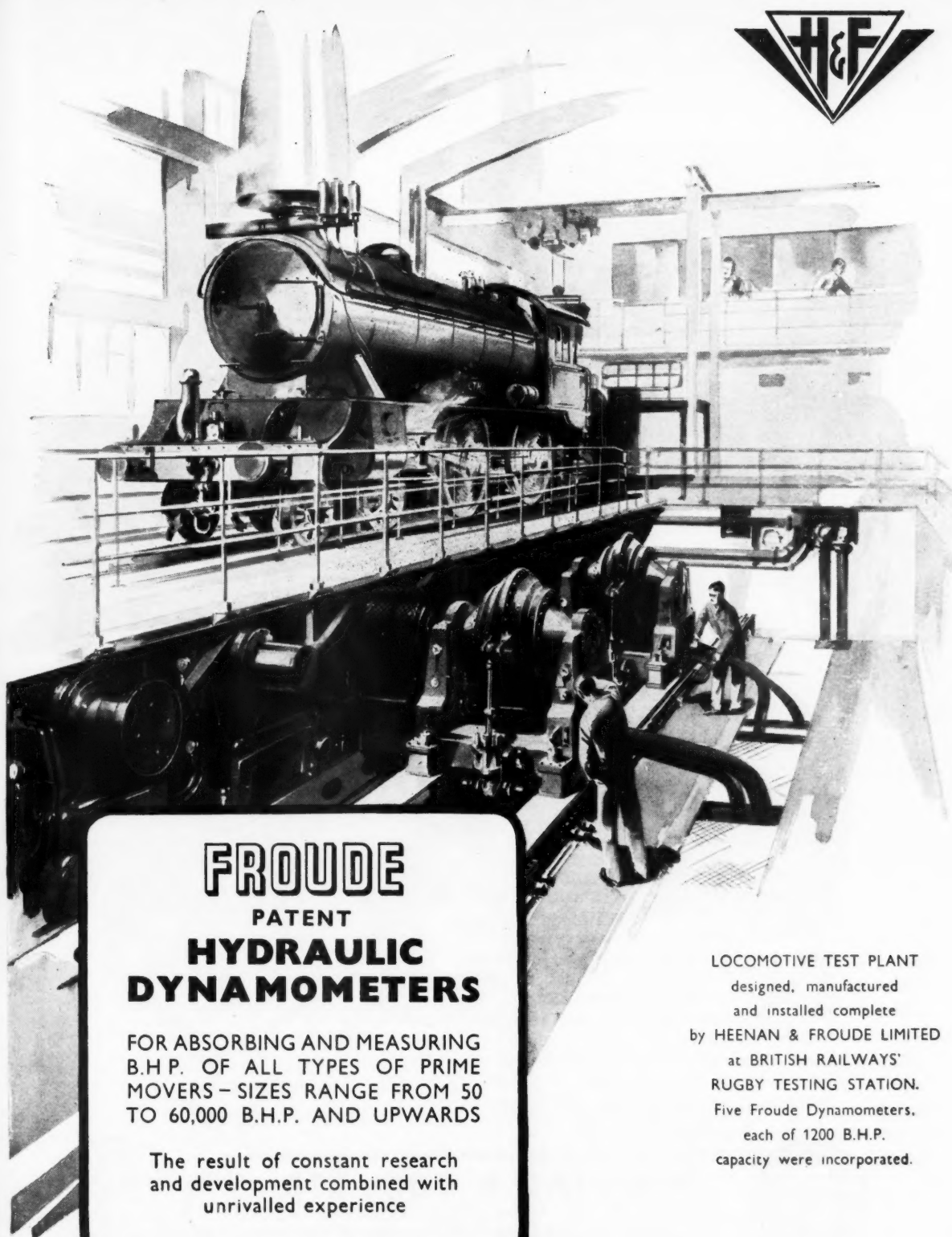
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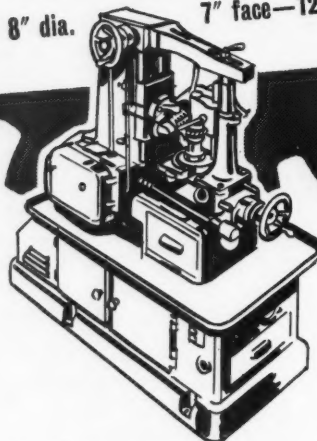
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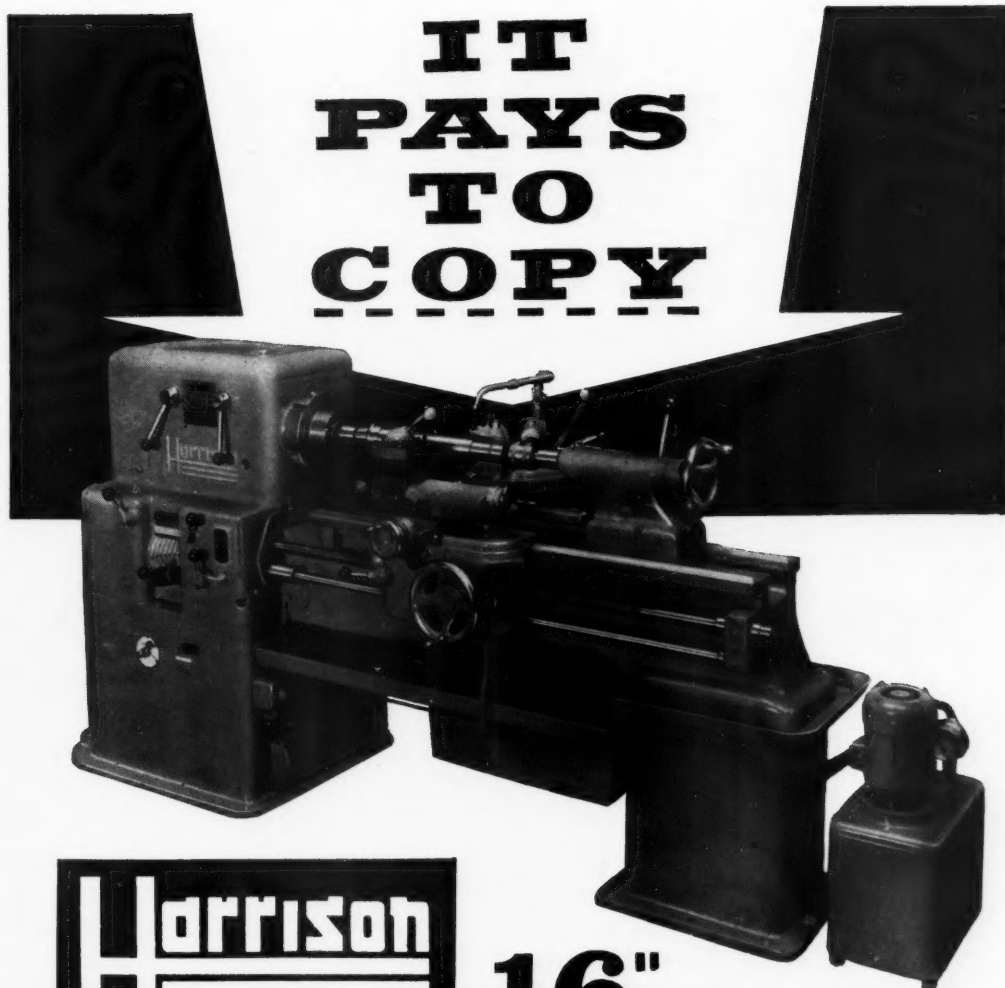
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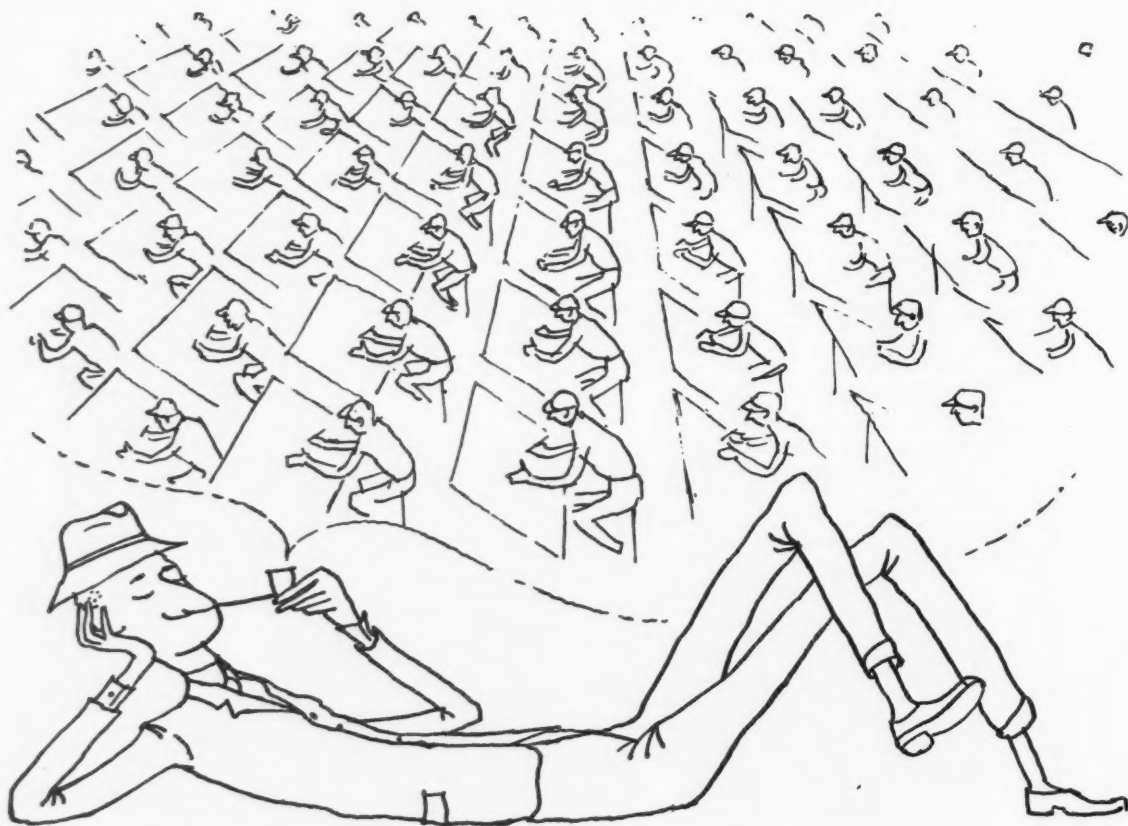
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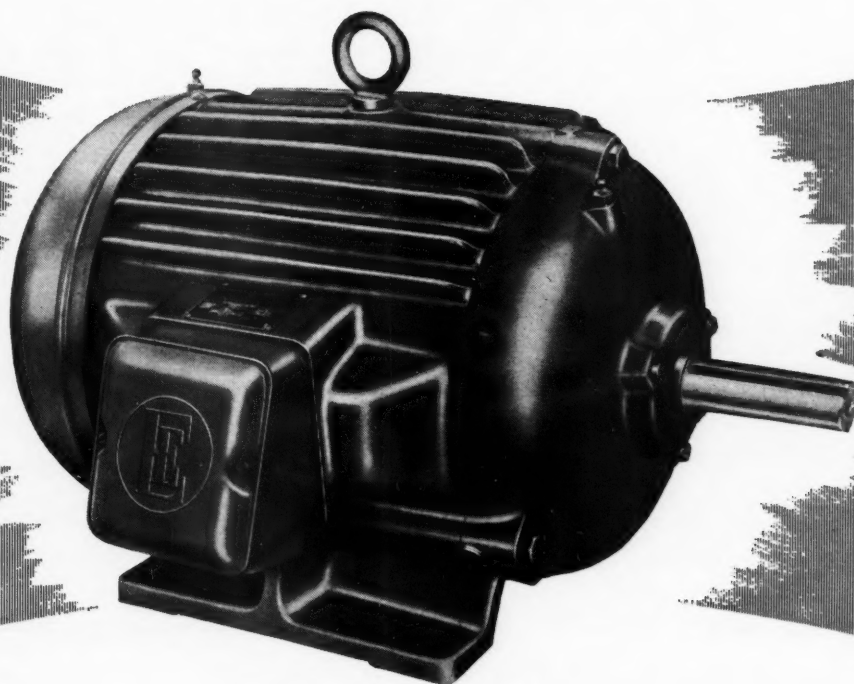
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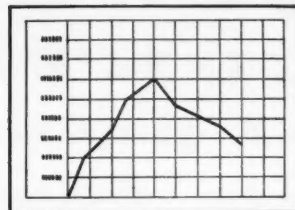
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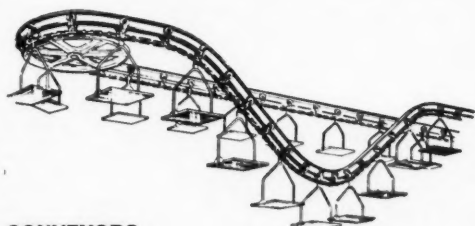


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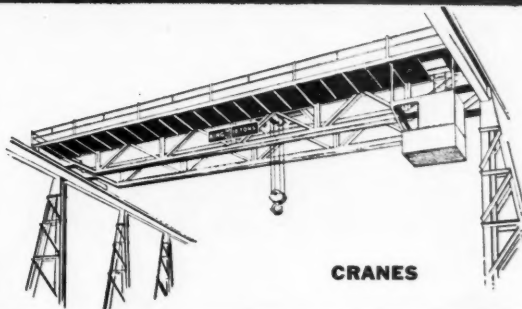


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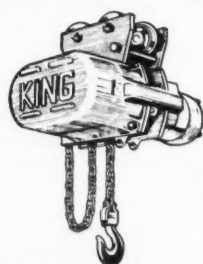
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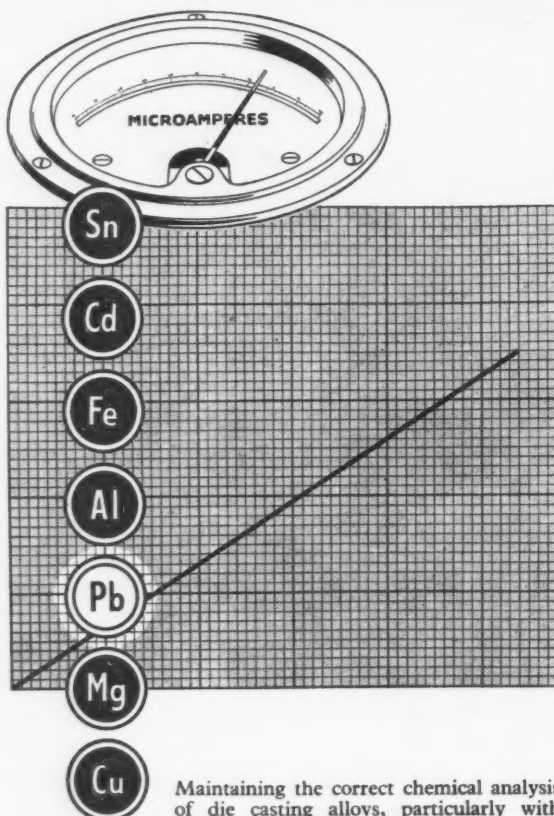
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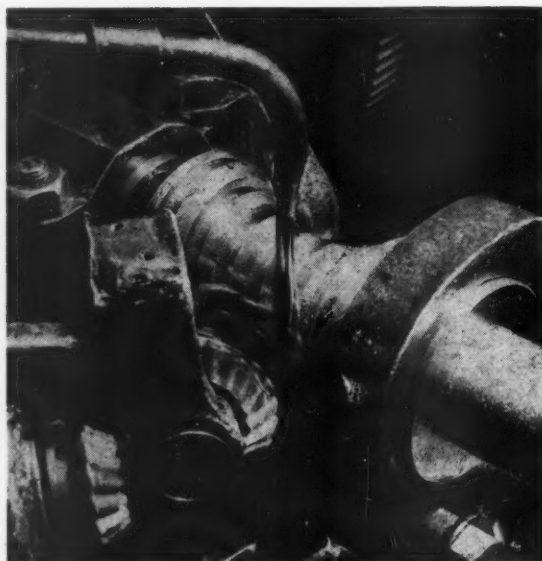
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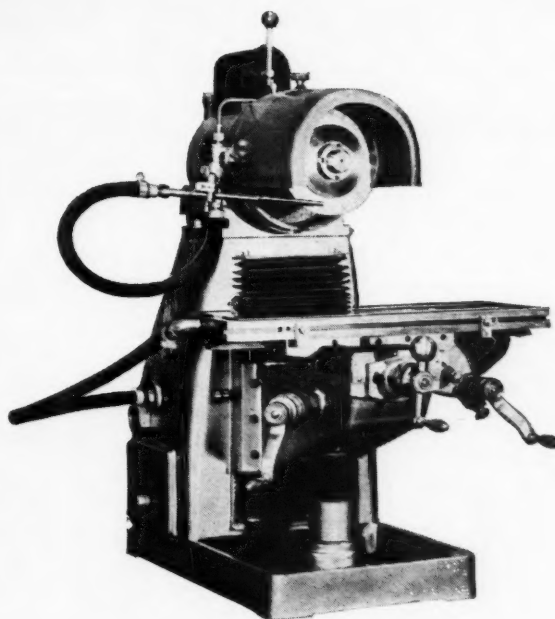


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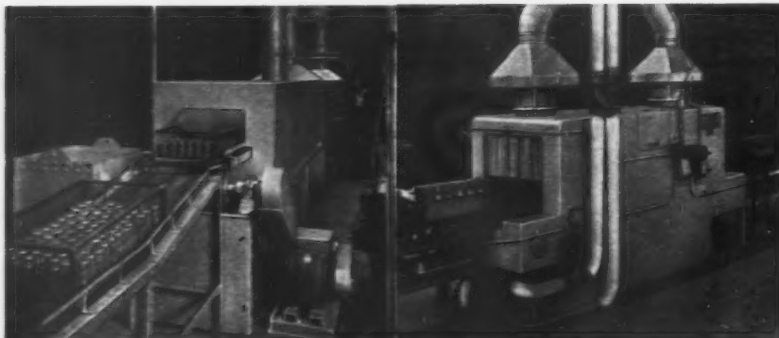
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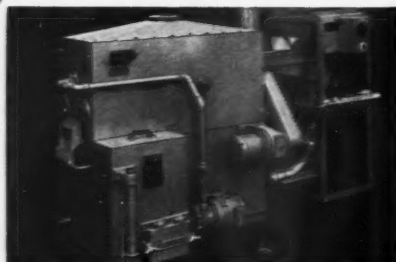


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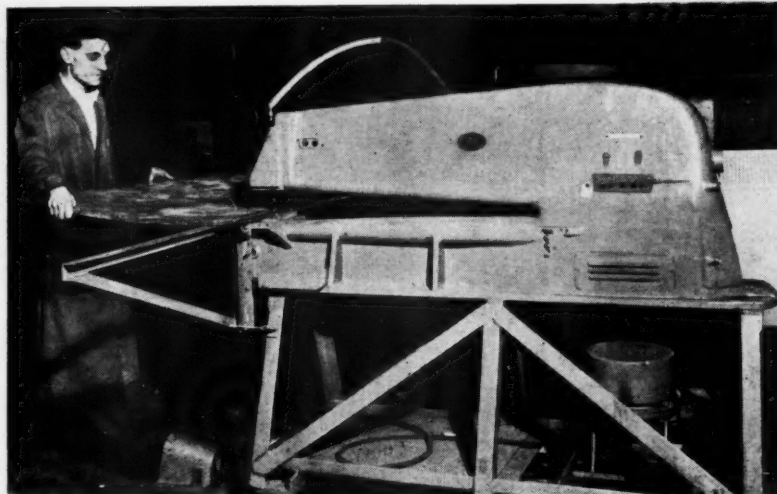
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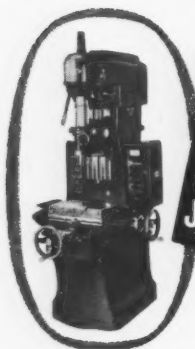
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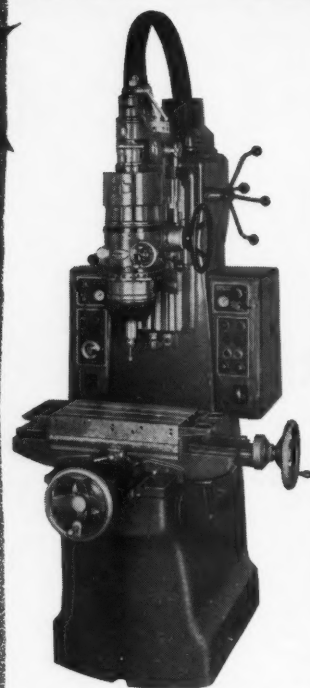
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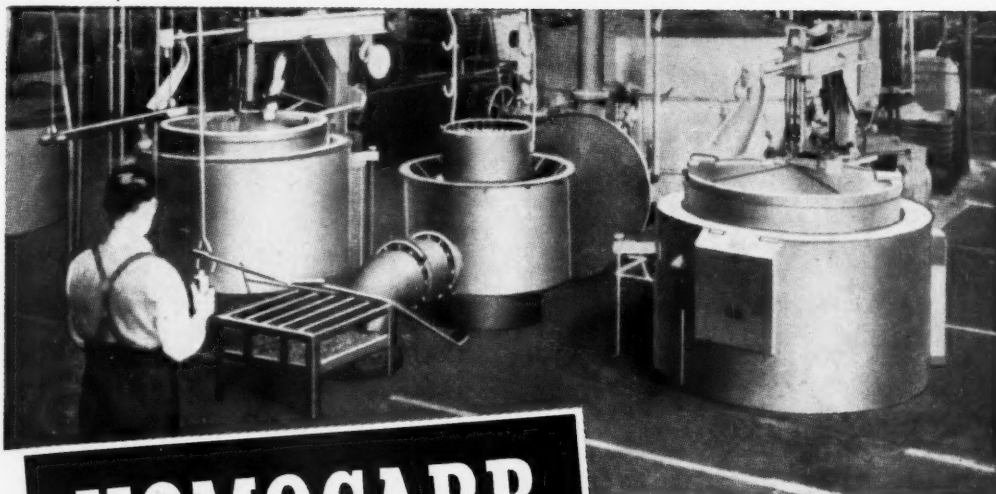
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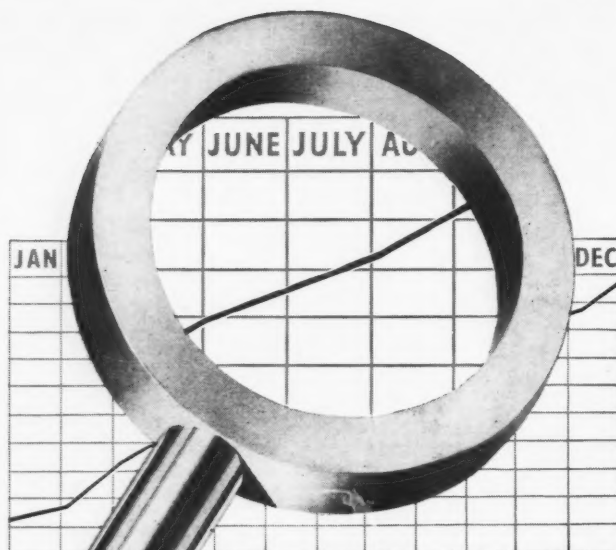
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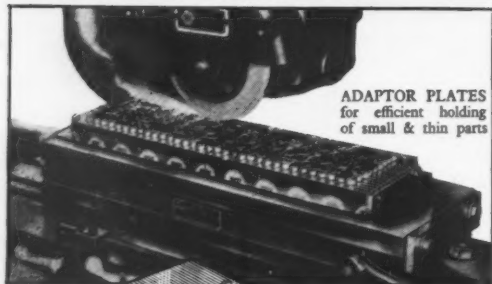
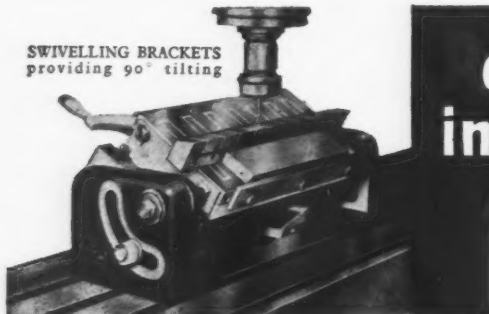


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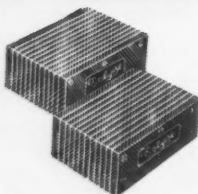
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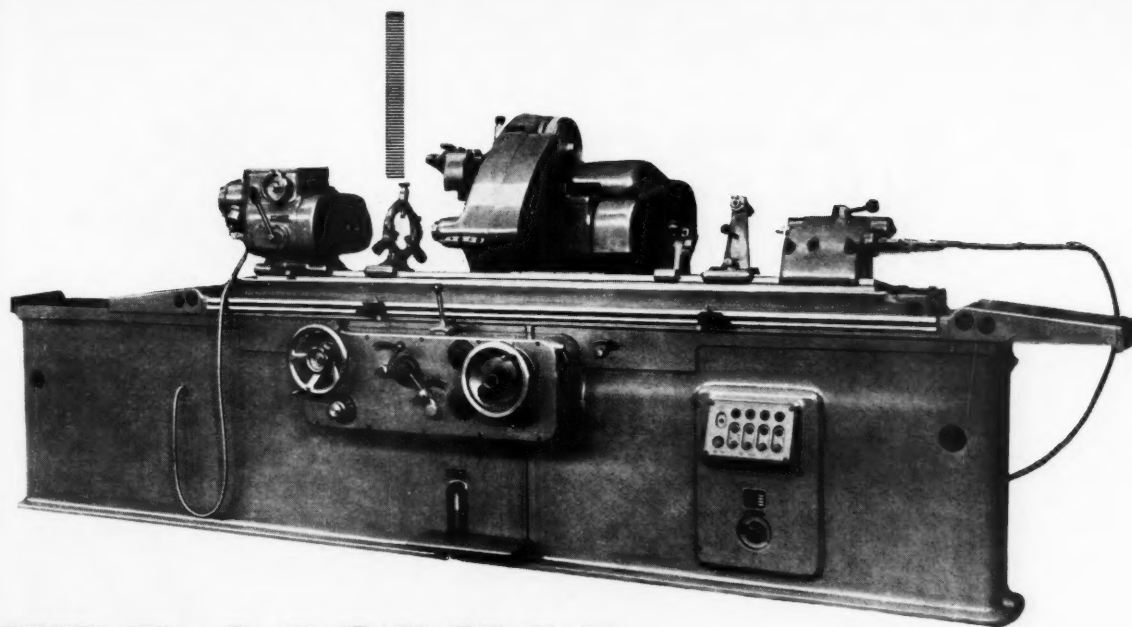
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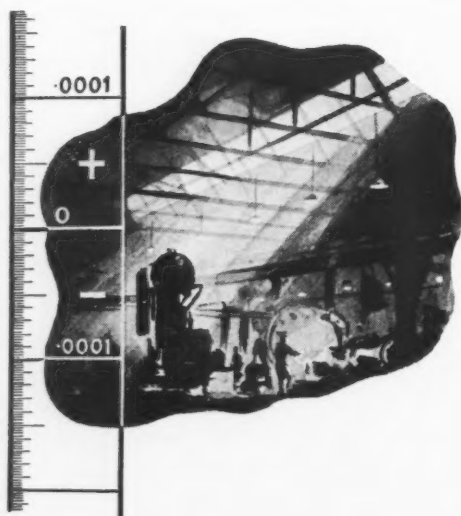
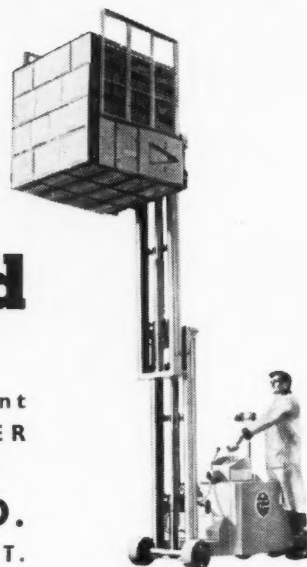
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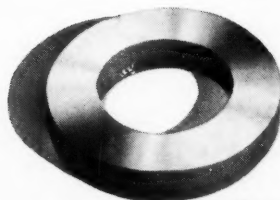
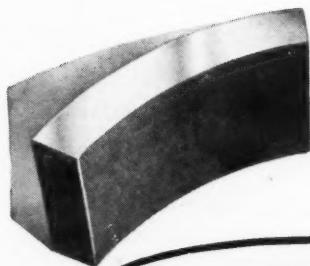
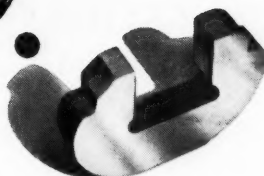
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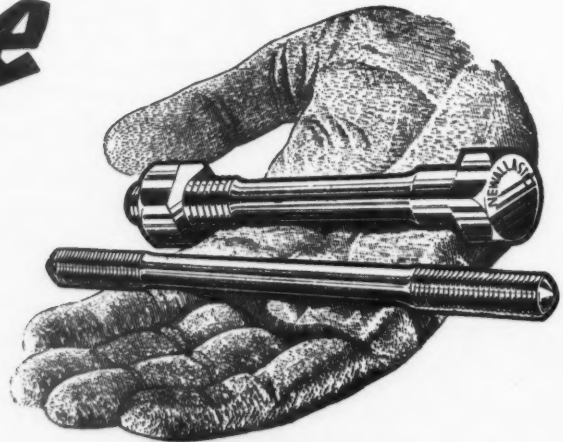
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. . . in fact any material through which electric  
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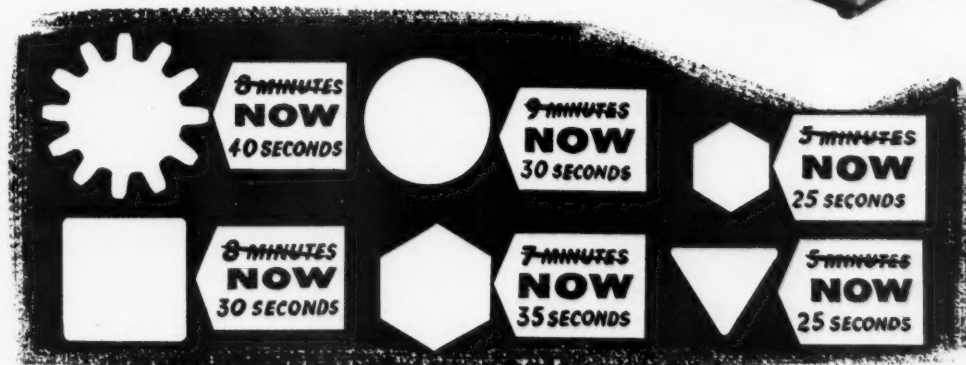
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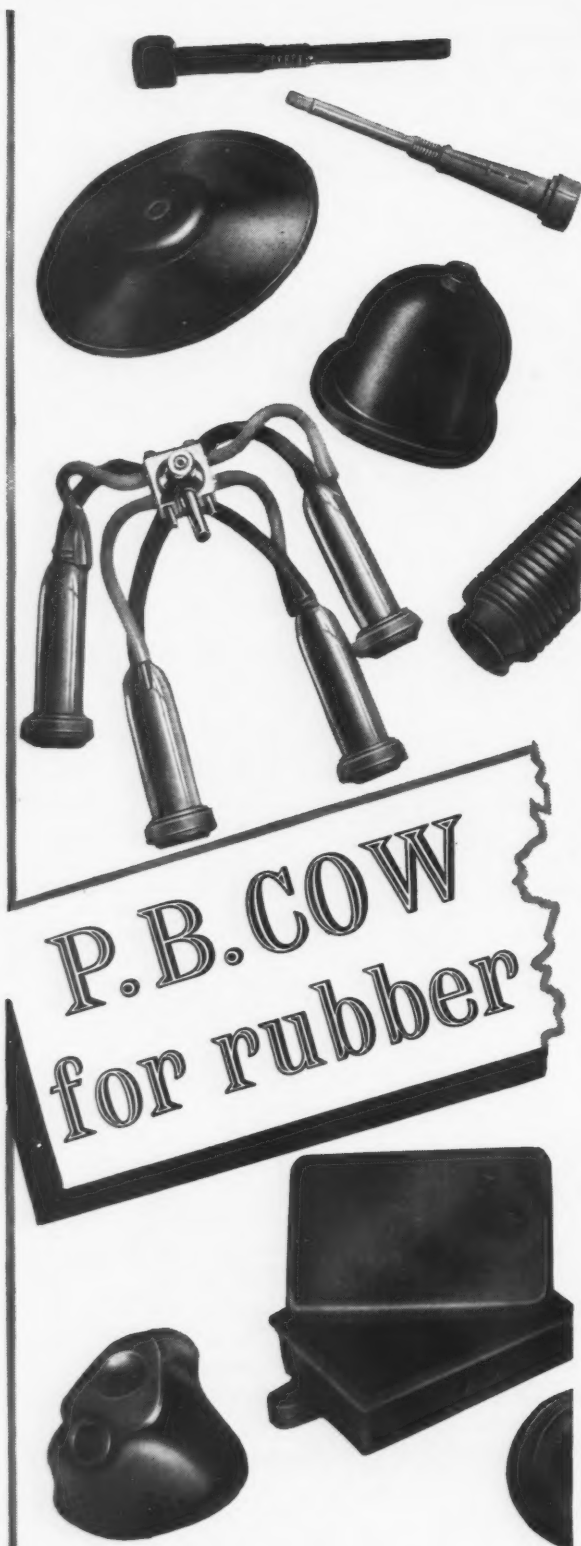
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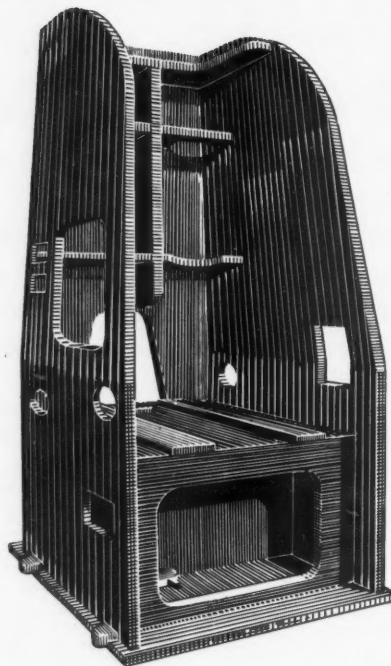
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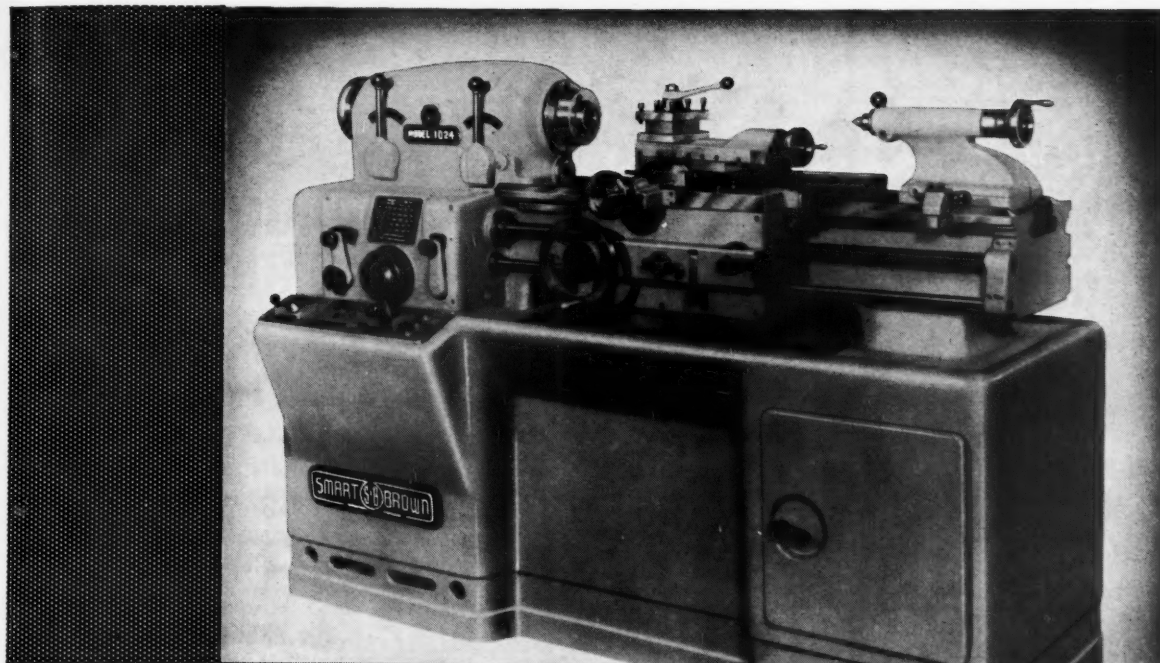
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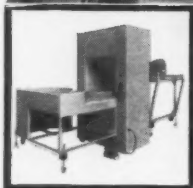
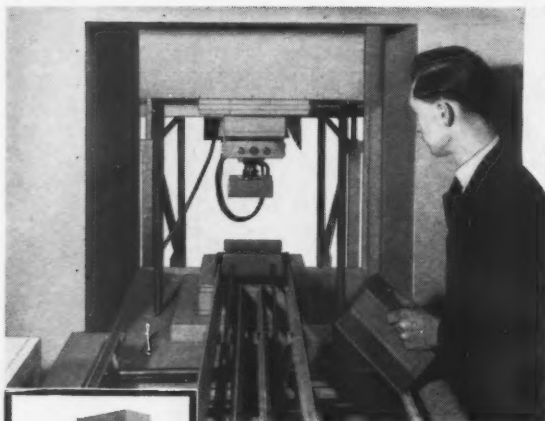
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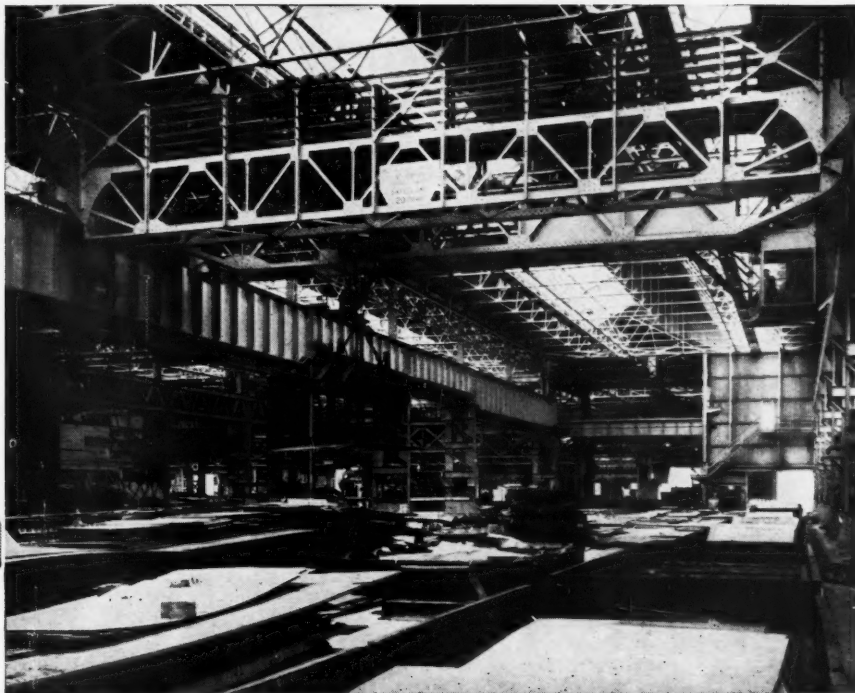
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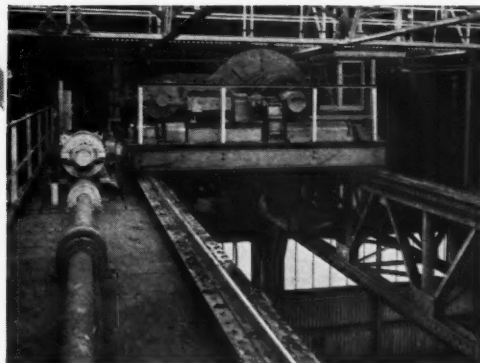
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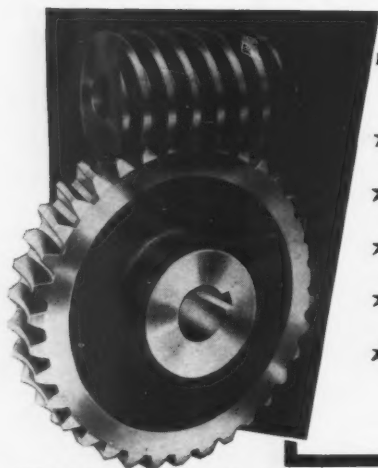
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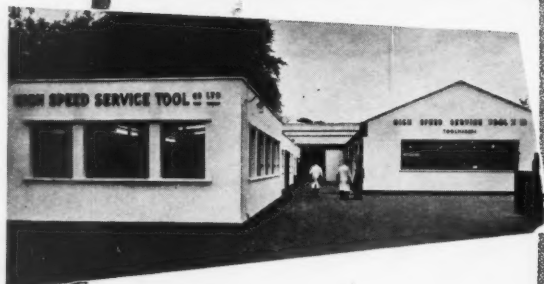
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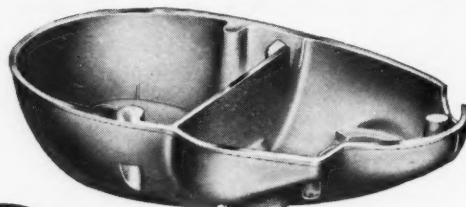


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on *Villiers* magneto covers

### PREVIOUS METHOD

Face milling on vertical miller

13

pieces per hour

### PRESENT METHOD

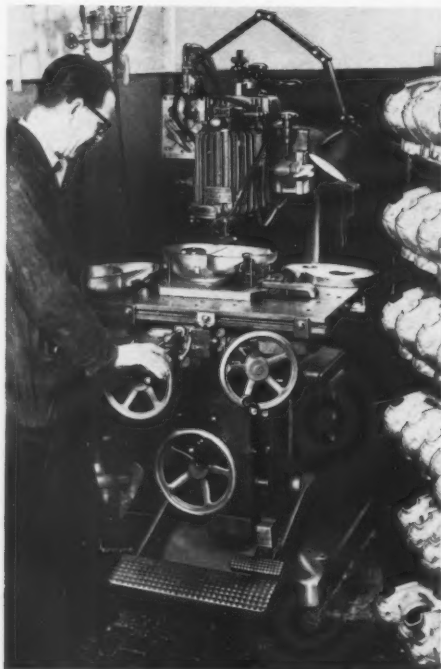
Face milling on Wadkin Router

32.4\*

pieces per hour

\* When the operator becomes fully proficient in the operation of the Wadkin Router, the rate of production is expected to reach 37 pieces per hour.

The Wadkin High Speed Router does the face-milling operation on this light alloy magneto cover with a saving of more than 60% of former machining time. This is not an unusual result — it's typical of the Wadkin Router's performance on Non-ferrous Metals. Unlike conventional machines the Wadkin L.S.M., shown on left, has cutting speeds up to 24,000 r.p.m. This guarantees a perfectly machined face requiring no further finishing operation, and only light clamping of the component is necessary.



# Wadkin

Tel: Leicester 67114

Wadkin Ltd., Green Lane Works, Leicester.

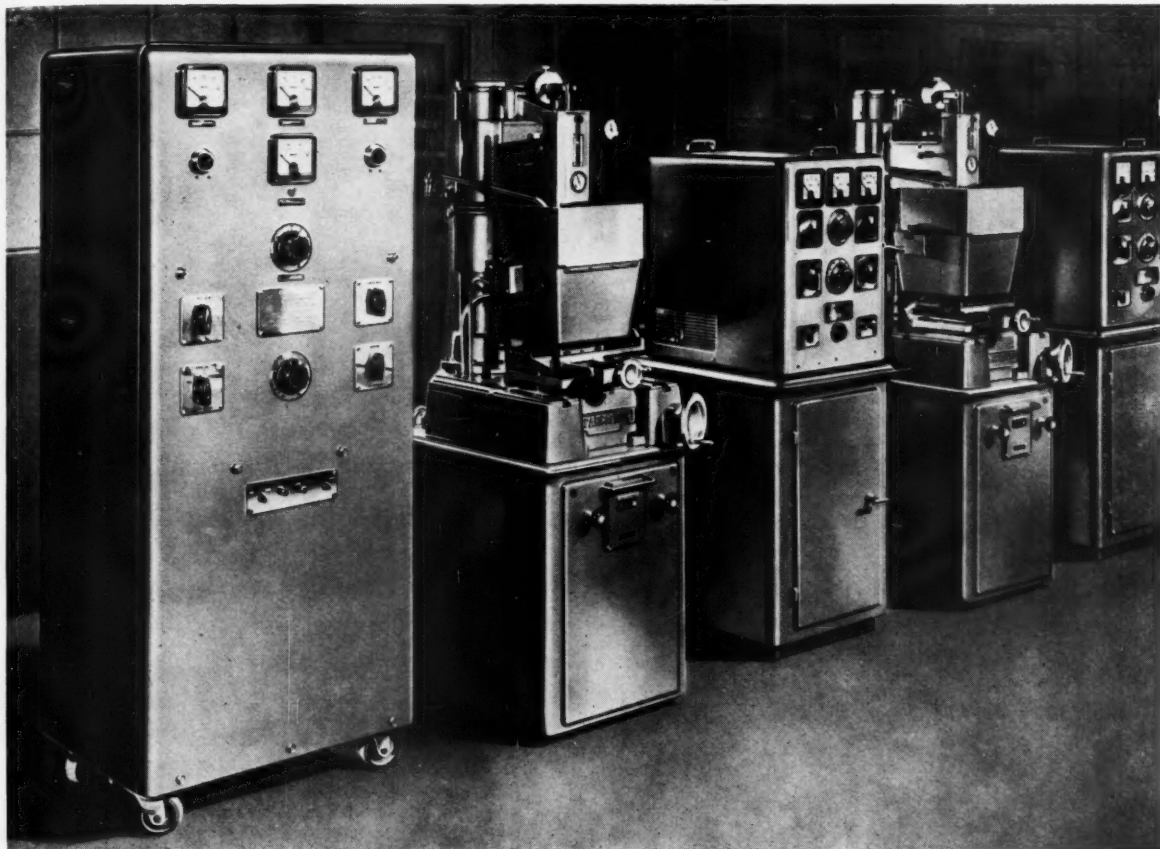
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## Mk III Model

6.5 KW

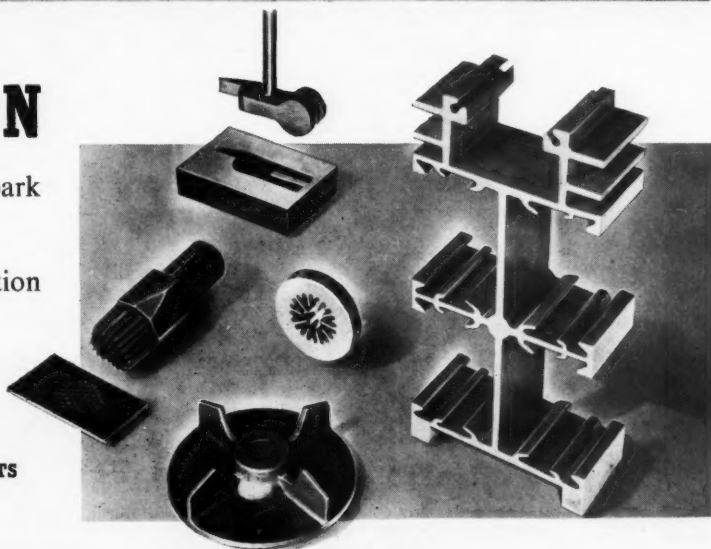


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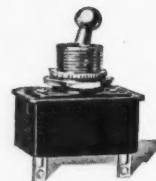


# Switches

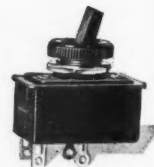
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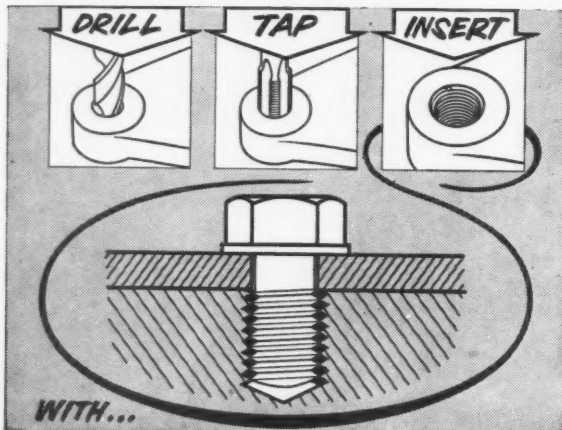
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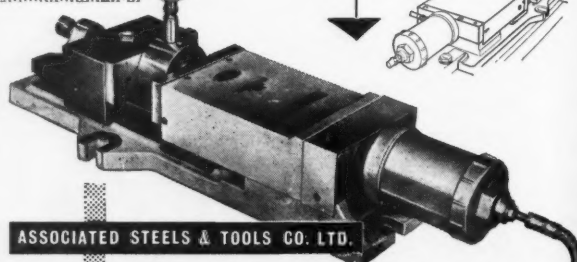
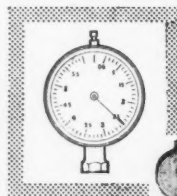
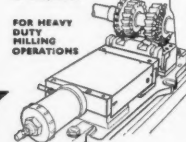
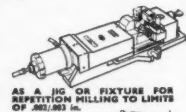
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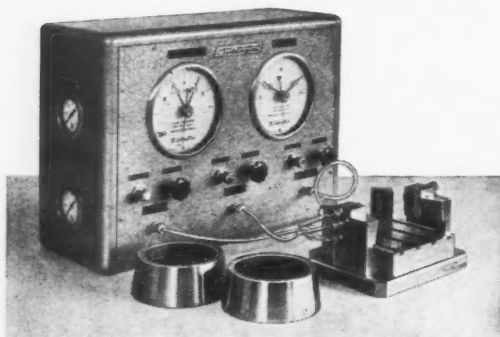
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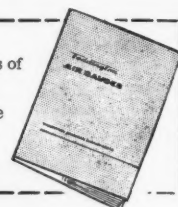
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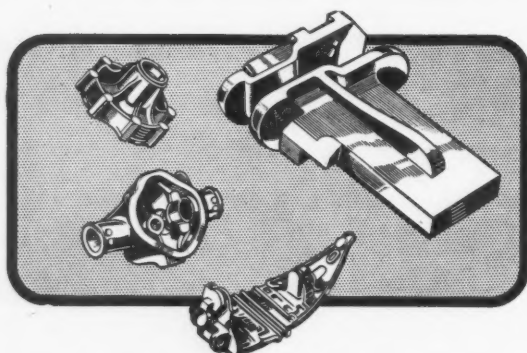
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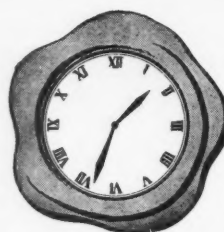
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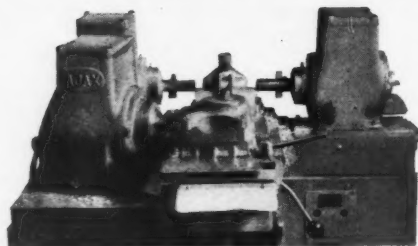
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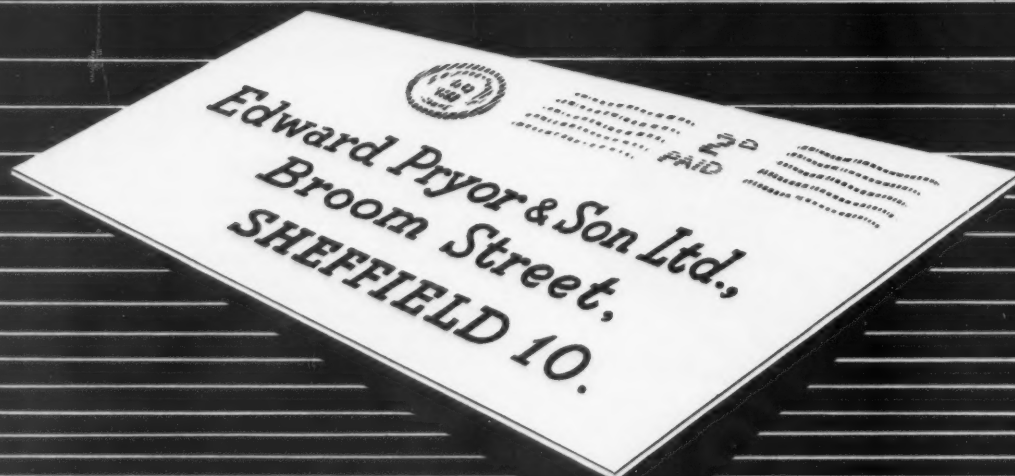
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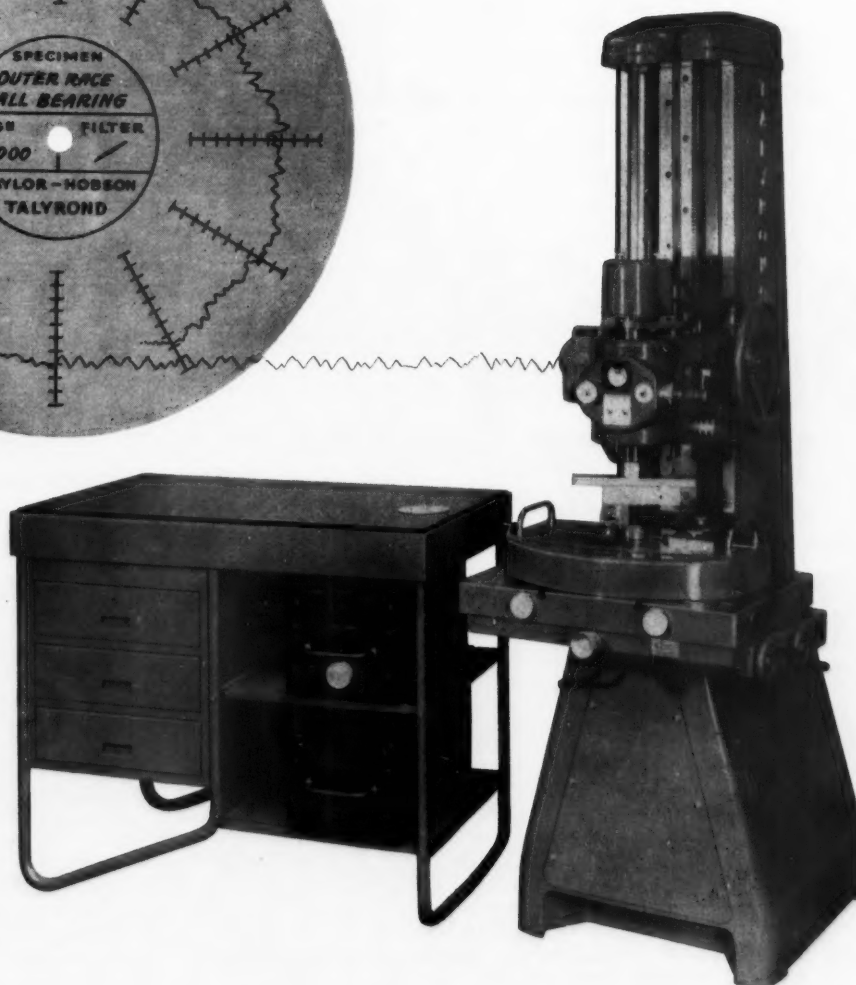
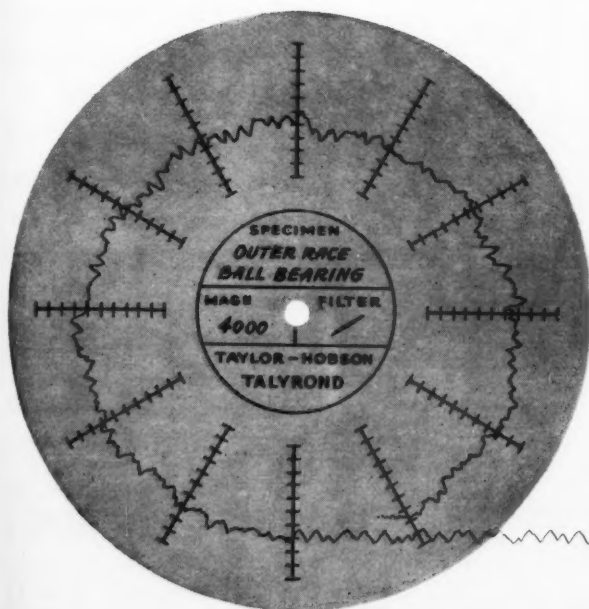
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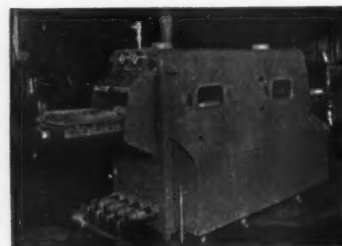
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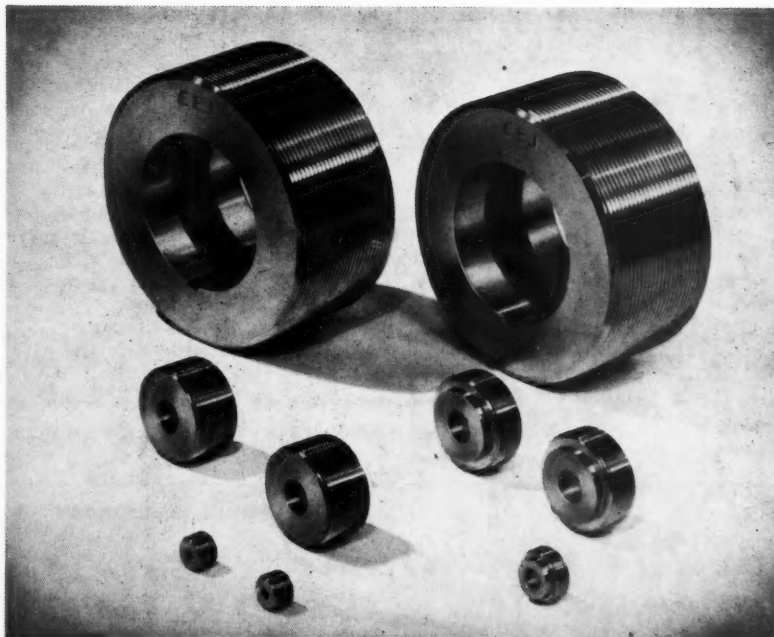
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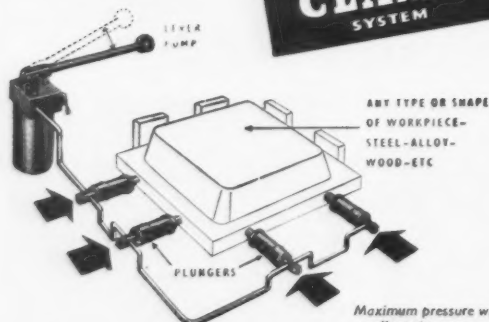
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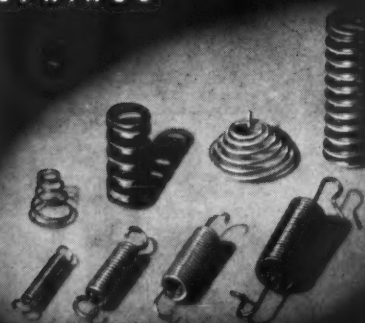
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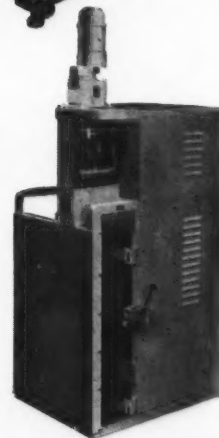
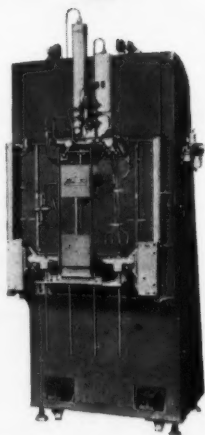
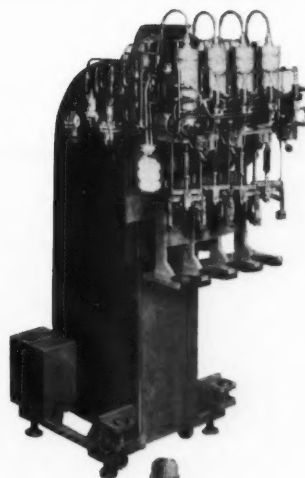
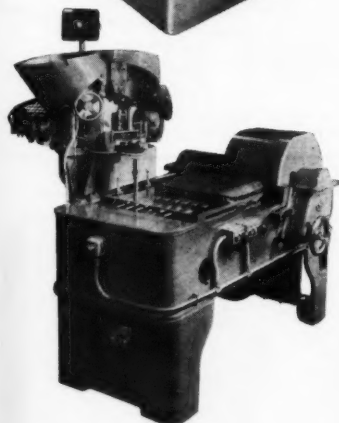
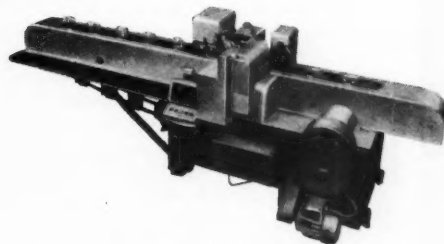
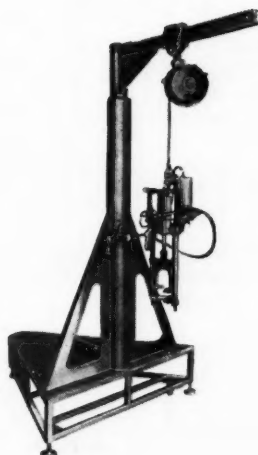
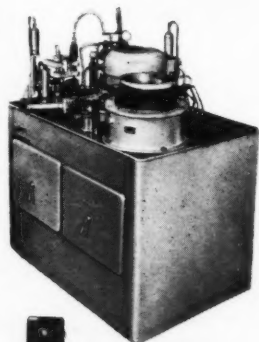
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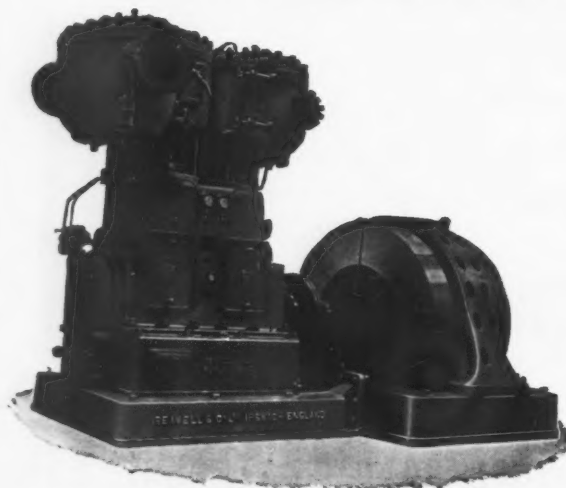
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## INDEX TO ADVERTISEMENTS

	Page		Page		Page
Adcock & Shipley, Ltd. ...	xx	Fletcher Miller, Ltd. ...	LXvi	Newall Group Sales, Ltd. ...	—
Aero Research, Ltd. ...	v	Ford Motor Co. Ltd. ...	—	New Conveyor Co. Ltd. ...	—
Ajax Machine Tool Co. Ltd. ...	LXXXviii	Fractional H.P. Motors, Ltd. ...	LXXXviii	Northern Aluminium Co. Ltd. ...	—
Allen, Edgar, & Co. Ltd. ...	xxiv	G.P.A. Tools & Gauges, Ltd. ...	LXXiv	Norton Grinding Wheel Co. Ltd. ...	xxxv
Allspeeds, Ltd. ...	xvii	Gas Council, The ...	—	Ofrex Group ...	—
Aluminium Wire & Cable Co. Ltd. ...	xxiii	Glacier Metal Co. Ltd. ...	xcii	Osborn, Samuel, & Co. Ltd. ...	—
Armstrong Patents Co. Ltd. ...	LXXXiv	Gledhill-Brook Time Records, Ltd. ...	LXXXvi	Park Gate Iron & Steel Co. Ltd. ...	—
Arrow Electric Switches, Ltd. ...	LXXXiv	Glostics, Ltd. ...	LViii	Parkinson, J., & Son (Shipley), Ltd. ...	xlvi
Asquith, William, Ltd. ...	L	Guest, Keen & Nettlefolds (Midlands), Ltd. ...	—	Paterson Hughes Eng. Co. Ltd. ...	xii
Associated Steels & Tools Co. Ltd. ...	LXXXiv	Guylee, Frank, & Son, Ltd. ...	—	Philips Electrical, Ltd. ...	—
Automation, Ltd. ...	—	Hale & Hale (Tipton), Ltd. ...	LXXXvi	Pitman, Sir Isaac, & Sons, Ltd. ...	xciv
B.S.A. Tools, Ltd. ...	vii	Harrison, T. S. & Sons, Ltd. ...	Lxi	Plannair, Ltd. ...	xvi
Baird & Tatlock (London), Ltd. ...	xix	Harris Tools, John, Ltd. ...	—	Power Jacks, Ltd. ...	xcii
Baker, C., of Holborn, Ltd. ...	LXviii	Heenan & Froude, Ltd. ...	Lix	Precision Grinding, Ltd. ...	xcv
Barber & Colman, Ltd. ...	—	Herbert, Alfred, Ltd. ...	xxxiii, lv	Pryor, Edward & Son, Ltd. ...	LXXXviii
Barracrough, R. W., Ltd. ...	xciii	High Speed Service Tool Co. Ltd. ...	LXXXii	Rack Engineering, Ltd. ...	xxii
Benton & Stone, Ltd. ...	xxviii	Hilger & Watts, Ltd. ...	—	Ratcliffe, F. S. (Rochdale), Ltd. ...	xcii
Birlec, Ltd. ...	—	Holman Bros., Ltd. ...	—	Rawplug Co. Ltd., The ...	xi
Birmingham Aluminium Casting (1903) Co. Ltd. ...	—	Holt, James (Engineers), Ltd. ...	—	Reavell & Co. Ltd. ...	xciv
Black & Decker, Ltd. ...	—	Hordern, Mason & Edwards, Ltd. ...	—	Reliance Gear & Eng. Co. (Salford), Ltd. ...	LXXXii
Bolton Railway Wagon & Ironworks Co. Ltd. ...	XL	Horstmann Gear Co. Ltd., The ...	—	Rockwell Machine Tool Co. Ltd. ...	xxv
Bratby & Hinchliffe, Ltd. ...	xc	Hydraulics & Pneumatics, Ltd. ...	LXXX	Rowland, F. E., & Co. Ltd. ...	LXXv
Bray Accessories, Ltd. ...	—	Hymatic Engineering Co. Ltd., The ...	x	Russell, S., & Sons, Ltd. ...	—
British Aero Components, Ltd. ...	—	Ilford, Ltd. ...	LXii	Ryder, Thos., & Son, Ltd. ...	—
British Die Casting & Engineering Co. Ltd. ...	iv	Impregnated Diamond Products, Ltd. ...	LXvii	Sandvik Swedish Steels, Ltd. ...	—
British MonoRail, Ltd. ...	xxxvi	Ingham, Robert, Clark & Co. ...	XLiv	Saville, J. J., & Co. Ltd. ...	Liii
British Oxygen Gases, Ltd. ...	—	Integra, Leeds & Northrup, Ltd. ...	LXxi	Scrivener, Arthur, Ltd. ...	—
British Tabulating Machine Co. Ltd. ...	—	Iota Services, Ltd. ...	XLv	Selson Machine Tool Co. Ltd., The ...	LXXXiii
British Thomson-Houston Co. Ltd. ...	—	Jessop, Wm., & Sons, Ltd. ...	Liii	Sentinel (Shrewsbury), Ltd. ...	—
British Timken, Ltd. ...	—	Johansson, C. E., Ltd. ...	xc	Servis Records, Ltd. ...	—
Brockhouse, J., & Co. Ltd. ...	—	Jones, E. H. (Machine Tools), Ltd. ...	—	Shell Chemical Co. Ltd. ...	xiii
Broom & Wade, Ltd. ...	LXix	Kaye, E. & E., Ltd. ...	—	Shell-Mex & B.P., Ltd. ...	xxxviii, xxxix
Brown, David, Corpn. (Sales) Ltd., The ...	—	Kearns, H. W., & Co. Ltd. ...	Lvi	Sheepbridge Equipment, Ltd. ...	LXXXviii
Brown & Ward, Ltd. ...	—	Keelavite Rotary Pumps & Motors, Ltd. ...	—	Smart & Brown (Machine Tools), Ltd. ...	LXXix
Burton Griffiths & Co. Ltd. ...	vii	King, Geo. W., Ltd. ...	LXv	Smith, C. & B., Ltd. ...	LXXvi
Butler Machine Tool Co. Ltd., The ...	LXXxi	Kingsbury, Geo. & Co. (Machine Tools), Ltd. ...	xiv	Smith, S. & Sons (England), Ltd. ...	—
Catmur Machine Tool Corpn., Ltd. ...	LXX	Lang, John & Sons, Ltd. ...	—	Snow & Co. Ltd. ...	—
Centec Machine Tools, Ltd. ...	—	Lang Pneumatic, Ltd. ...	viii	Société Genevoise, Ltd. ...	xxi
Churchill, Charles & Co. Ltd. ...	—	Lapointe Machine Tool Co. Ltd. ...	—	Sogenique (Service), Ltd. ...	—
Churchill Machine Tool Co. Ltd. ...	—	Ley's Malleable Castings Co. Ltd. ...	—	Solex (Gauges), Ltd. ...	xxx
Churchill-Redman, Ltd. ...	—	Lincoln Electric Co. Ltd., The ...	ix	Sparcatron ...	LXXXiii
Ciba (A.R.L.), Ltd. ...	v	Lloyd, F. H. & Co. Ltd. ...	xxxiv	Sparklets, Ltd. ...	LXvi
Climax Rock Drill & Eng. Works Ltd. ...	—	Lloyd, Richard, Ltd. ...	LXXXv	Spencer & Halstead, Ltd. ...	—
Cohen, Geo., Sons & Co. Ltd. ...	xciv	Lodge Plugs, Ltd. ...	—	Square, D., Ltd. ...	—
Concentric Manufacturing Co. Ltd. ...	—	London Oil Refining Co. Ltd., The ...	LXXiv	Sternol, Ltd. ...	—
Cooper & Co. (B'ham), Ltd. ...	—	Lund, John, Ltd. ...	LXXXvii	Sunbeam Anti-Corrosives, Ltd. ...	LXiv
Coventry Climax Engines, Ltd. ...	—	M.H.H. Engineering Co. Ltd. ...	—	Swift, Geo., & Sons, Ltd. ...	—
<i>Outside Back Cover</i>		Macready's Metal Co. Ltd. ...	XL	Swift Summerskill, Ltd. ...	—
Coventry Gauge & Tool Co. Ltd. ...	XLi	Magnesium Elektron Co. Ltd. ...	XXix	Sykes Machine Tool Co. Ltd., The ...	—
Cow, P. B., & Co. Ltd. ...	LXXXviii	Manganese Bronze & Brass Co. Ltd. ...	—	Sykes, W. E., Ltd. ...	—
Crawford Collets, Ltd. ...	—	Marbaix, Gaston E., Ltd. ...	—	Talbot Tool Co. Ltd., The ...	iii
Crofts (Engineers), Ltd. ...	xxvi, xxvii	Marbaix Industries, Ltd. ...	LXXvii	Taylor, Taylor & Hobson, Ltd. ...	LXXXix
Crompton Parkinson (Stud Welding), Ltd. ...	—	Markland Scowcroft, Ltd. ...	LXXii	Teddington Industrial Equipment Ltd. ...	LXXXvi
Crosland, William, Ltd. ...	—	Marsden & Shiers, Ltd. ...	xc	Terry, Herbert, & Sons, Ltd. ...	—
Daniels, T. H. & J., Ltd. ...	xxxiii	Martonnair, Ltd. ...	—	Town, Frederick & Sons, Ltd. ...	xviii
Dawe Instruments, Ltd. ...	—	McGraw-Hill Publishing Co. Ltd. ...	—	Udal, J. P., Ltd. ...	LXXX
Dawson Bros., Ltd. ...	LXviii	<i>Inside Back Cover</i>		Unbrako Socket Screw Co. Ltd. ...	—
Dean Smith & Grace, Ltd. ...	xxxvii	<i>Inside Back Cover</i>		Universal Tools, Ltd. ...	LXXX
Dowding & Doll, Ltd. ...	LX	Metropolitan-Vickers Electrical Co. Ltd. ...	—	Vacu-Blast, Ltd. ...	LXX
Drummond Asquith (Sales), Ltd. ...	Lii	Midgley & Sutcliffe, Ltd. ...	—	Van Moppes & Son (Diamond Tools), Ltd. ...	Liv
Drummond Bros., Ltd. ...	Li	Minnesota Mining & Manufacturing Co. Ltd. ...	xxxii	Vaughan Associates, Ltd. ...	XLix
E.M.I. Electronics, Ltd. ...	—	Mobil Oil Co. Ltd. ...	XLiii	Wadkin, Ltd. ...	LXXXii
E.N.V. Engineering Co. Ltd. ...	xc	Monks & Crane, Ltd. ...	—	Wakefield-Dick Industrial Oils, Ltd. ...	—
Edibrac, Ltd. ...	—	Morris, B. O., Ltd. ...	xv	Ward, H. W., & Co. Ltd. ...	XLvii
Elgar Machine Tool Co. Ltd. ...	—	Napier, D., & Son, Ltd. ...	—	Ward, Thos. W., Ltd. ...	—
Elliott Bros. (London), Ltd. ...	—	National Industrial Fuel Efficiency Service ...	—	Webster & Bennett, Ltd. ...	xxx
Elliott, B. (Machinery), Ltd. ...	—	Neill, James & Co. (Sheffield), Ltd. ...	LXXii	Welsh Metal Industries, Ltd. ...	—
English Electric Co. Ltd., The ...	LXiii	Newall, A. P., & Co. Ltd. ...	LXXvi	Wickman, Ltd. ...	XLii
English Steel Tool Corpn., Ltd. ...	—	Newall Engineering Co. Ltd. ...	LVii	Wild-Barfield Electrical Furnaces, Ltd. ...	—
Exors of James Mills, Ltd. ...	vi			Woodhouse & Mitchell ...	—
Firth, Thos. & Brown, John, Ltd. ...	—				
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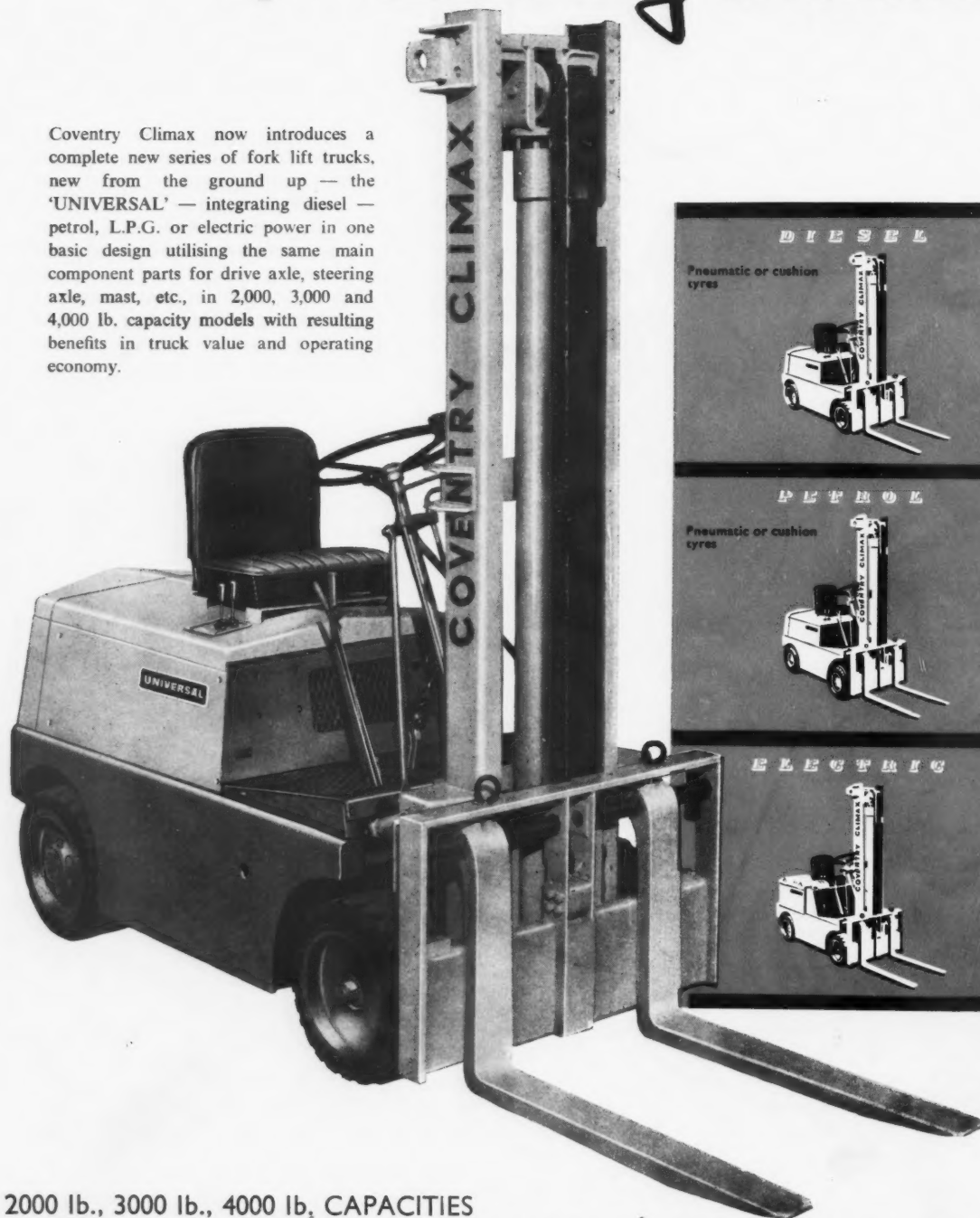
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